Viability of the Dutch Inland Waterway Transport Sector

IN THE CONTEXT OF THE FUTURE NAVIGABILITY OF THE RHINE

RONALDUS H.A. LASSOOIJ

TU Delft

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by

RONALDUS H.A. LASSOOIJ
4583167

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PROF.DR. FRANS KLIJN | CHAIRMAN
DR.IR. C. ELS VAN DAALEN | FIRST SUPERVISOR
DR. STEFANO FAZI | SECOND SUPERVISOR
DR.IR. JOS S. TIMMERMANS | EXTERNAL SUPERVISOR

Preface

DEAR READER,

As the culmination of a five-year period of tertiary education at the Delft University of Technology, I write these final words of my report on my thesis research project with pride and enthusiasm.

This thesis research project started as a discussion between me and my supervisor in the early months of 2021 on the stress that climate change exerted on the Dutch inland waterway transport sector. Although the technical field of inland waterway transport was unknown to me, it piqued my curiosity precisely for that reason. I quickly dove into the literature on the sector and held interviews with kind and open-hearted experts throughout the sector. The interactions and conversations with these experts gave recognition to my work and motivated me throughout the process of working on my thesis research project.

As restrictions of the COVID-19 pandemic began to loosen in second half of the year, I even managed to organize visits to meet experts in the field. Being present at the site of my research gave me a greater understanding of what my thesis research project was contributing towards. It also opened my eyes to the reality of the decision-making process my research was supporting, which is something that I did not fully grasp while sitting in the confinement of my student home during the previous time spent under lockdown. This ultimately gave me sense of accomplishment and a feeling of contribution.

I would like to express my thanks to all my committee members for their contribution towards my thesis research project. My most sincere gratitude goes to Jos Timmermans and Floortje d'Hont (previously part of my graduation committee) for their guidance, advice, and personal support throughout my graduation process. They helped me through tough times by giving me the inspiration and encouragement I needed. Furthermore, I sincerely like to thank all of the friends who have supported me through providing feedback and encouragement during the writing of this thesis research project.

Lastly, I would like to thank my parents who have always been encouraging of my life decisions and supportive of my ambitions. They stood beside me when I made the decision to study in Delft and have made the effort to visit me often while I was studying abroad. Although the COVID-19 pandemic makes travel difficult, I will be happy to see them once I finish working on my thesis research project.

This thesis research project marks the end of my student career. I hope that you, the reader, will enjoy reading this report as much as I enjoyed finishing it.

RONALDUS H.A. LASSOOIJ

Delft, December 2nd, 2021

Reading Guide

Before reading the report of this thesis research project, please take note of some details with regards to how this report should or can be read.

This report regularly uses field-specific vocabulary that may not automatically be intelligible to the readers outside of the field of inland waterway transport. Furthermore, some vocabulary might have ambiguous definition and therefore may require further specification of the exact definition that is used in this report so that confusion is avoided. A *glossary* at the end of this report provides the definitions for the vocabulary used in this report. Every term entry is marked in italics the first time it is mentioned within a chapter to show that its definition can be found in the glossary. The glossary also contains Dutch and German translations of term entries to clarify the equivalent terms in the languages that the Dutch inland waterway transport sector operates in.

Throughout this report, references are made to interviews with various experts. The specific identity of each expert has been concealed by reducing it to a generic code. A complete list of the generic codes and further anonymized information on the experts can be found on *page 99*.

When viewing this report digitally through a PDF viewer, it is possible to navigate the report using hyperlinks. This report contains many different hyperlinks that direct you, the reader, to different parts of the report, which give more context to the hyperlinked text. These hyperlinks are marked by *italics*. Hyperlinked items include referred page numbers and chapters, glossary vocabulary, abbreviations, in-text citations, cited experts and website links in the bibliography.

The text in this report is written in Canadian English.

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List of Acronyms

CCNR	Central Commission for Navigation on the Rhine
COV	Centraal Overleg Vaarwegen
EU	European Union
GHG	Green House Gases
GLQ	Gleichwertiger Abfluss
GLW	Gleichwertiger Wasserstand
IWT	Inland Waterway Transport
LRD	Low river depth

Executive Summary

At the UN conference of 2015, the promotion of *inland waterway transport* (*IWT*) was named as a Sustainable Development Goal by the United Nations (*United Nations Economic Commission for Europe, 2018*). While IWT has been identified to make goods transport more CO2-efficient, the long-term viability of the Dutch IWT sector is at risk.

Currently, Dutch IWT businesses benefit from increased demand for transport capacity during climate change induced periods of low river depth by being able to charge higher prices to shippers, thereby increasing short term profits. This thesis research project concludes that this behaviour is unsustainable due to the disregard for providing price competitive and reliable services to shippers, which will ultimately damage the reputation of the Dutch IWT sector. This can lead to shippers choosing other modes of transport, which will damage the long-term viability of IWT demand.

A lack of evident optimal climate adaptation measures that would better guarantee the long-term viability of an IWT business under any climate scenario is one of the reasons why IWT businesses have thus far been hesitant towards implementing climate adaptation measures. This thesis research project studies the potential of using a robust decision analysis in supporting IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector. It conducts a robust decision analysis and then evaluates its potential using feedback from stakeholders of the Dutch IWT sector.

Firstly, this study collects information on the characteristics of the IWT sector that create IWT demand, the various uncertain development affecting the Dutch IWT sector in context of the future navigability of the Rhine and what measures IWT businesses have at their disposal to combat these developments. It conducts a desk study and interviews 17 different stakeholders in the Netherlands and Germany to gather this information. This study identifies that price competitiveness and reliability form the characteristics that attract IWT demand from shippers. Furthermore, this study recognizes two major uncertain developments that influence the Dutch IWT sector in the context of the future navigability of the Rhine. The manifestation of future low river depth periods with regards to their intensity, frequency and duration and the proportion to which future IWT demand will be composed of container transport demand are the two major uncertain developments identified in this thesis research project. The measures that this thesis research project identifies are composed of measures

that target changes to fleet management, changes to logistical operations and using data in innovative ways to plan ahead.

Secondly, this thesis research project uses the gathered information to produce an influence diagram that summarizes the relations between uncertain future developments, climate adaptation measures and their effects on the long-term IWT demand viability. Using the influence diagram as a tool, this thesis research projects conducts a robust decision analysis that qualitatively evaluates the robustness of the proposed measures under various scenarios. The robust decision analysis conducted by this thesis research project has established that internal measures differ in their robustness under different scenarios with regards to the navigability of the Rhine. Measures that involve using data in an innovative manner are relatively robust due to their low investment costs and the fact that they change little to the current logistical processes. Measures with higher investment costs such as the deployment of low draught barges or measures that require continual expenditure like the reservation of additional transport capacity on other modes of transport are less robust when confronted with scenarios in which low river depth periods occur less intensely, frequently or time-extensively and container transport is the predominant type of transport good transported by IWT businesses.

Lastly, this thesis research project presents the influence diagram and the results from the robust decision analysis to IWT stakeholders to evaluate how these could impact their decision-making. Stakeholders noted that they believe that the produced influence diagram could be used as a standard communication object to produce a better consensus of how measures influence the long-term viability of IWT demand. Furthermore, stakeholders expressed that the robust decision analysis provided them a better understanding of which measures were able to better guarantee the long-term viability of IWT demand. Results from evaluation interviews with stakeholders therefore provide grounds to believe that robust decision analyses have potential to support IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector.

1 Introduction

1.1 Problem Context

When transporting large volumes over long distances (i.e., 100km+), *inland waterway transport* (*IWT)* offers an apparent advantage in terms of the energy consumption per *tonne-kilometre* compared to road transport (*Telesca, 2015*). Transport by road typically consumes three times the energy per tonne-kilometre as transport by inland waterway (*CE Delft, Directorate-General for Mobility and Transport, INFRAS, & Ricardo, 2019*; *Figee & Volker, 2015*). Additionally, a standard 110 m-long barge transports the equivalent tonnage of 100 journeys of a 40-ton truck, which lead to economic savings via economies of scale (*Figee & Volker, 2015*).

The energy-efficiency that IWT offers with regards to road transport has led to the development of extensive inland waterway networks in regions with prevalent river systems (*Bonnerjee et al., 2009*). By virtue of being located on the *Rhine Estuary*, the Netherlands is home to one of the most important inland waterway networks in the world (*Cioc, 2002*; *Figee & Volker, 2015*). Its 6300 km IWT network has enabled the establishment of an IWT sector, which has become an integral pillar of the Dutch freight transport system (*Statistics Netherlands, 2019*, *2020b*). In 2019, the IWT sector transported 42% of all freight (see *Figure 1.1*) and more than half of the incoming and outgoing international containers between the Port of Rotterdam and the European *hinterland* (*Port of Rotterdam, n.d.*), thereby, on its own, contributing €2.6 billion to the Dutch economy (*Statistics Netherlands, 2019*).

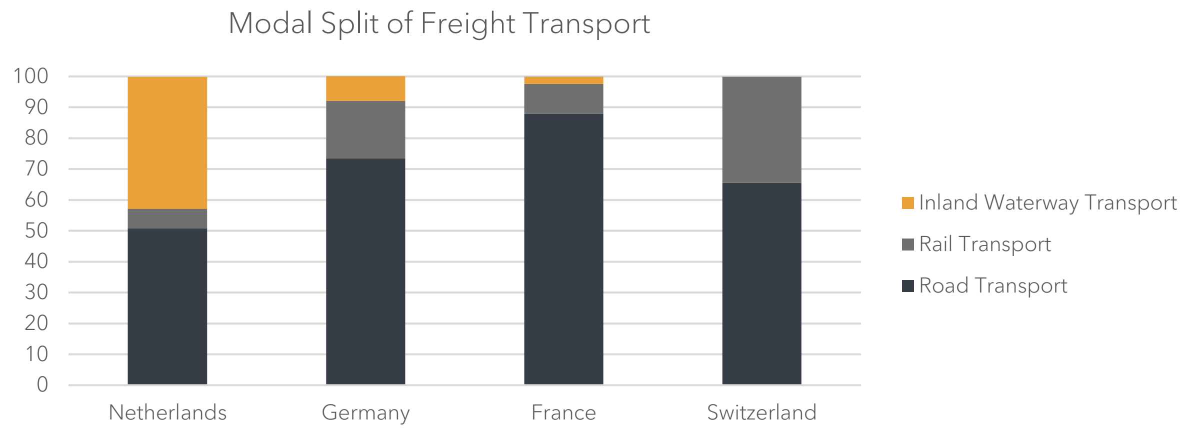

*Figure 1.1 | Modal split of freight transport in Rhine riparian states in 2019 (*Eurostat, 2021*)*

The central asset in the Dutch waterway network are the *distributaries* of the Rhine, which hands *shippers* unhindered access to 620 km of passage over Rhine, connecting the Port of Rotterdam and other *seaports* in Netherlands to *inland ports* in Germany, France and Switzerland (*Euwe, 2012*; *Nilson & Krahe, 2019*; *Notteboom, 2017*). The combination of IWT's energy-efficiency and the Rhine's accessibility has led to the development of an IWT sector in the Netherlands over the last few centuries that is only second to that of the Mississippi and its delta[1] (*Wilken, 2006*).

In the 21st century, IWT's characteristic of being energy-efficient and the extensive Rhine inland waterway network has brought attention to the IWT sector as policymakers look for ways of making container transport more *CO_2-efficient*. The recent *European Green Deal* has committed the European Union (*EU*) to shifting container transport away from road transport by increasing the transportation of containers by inland waterway by 50% until 2050 (*European Commission, 2019*; *Schwanen, 2021*). In relation to EU's plans, the governments of the Netherlands and Germany have also outlined national *modal shift* ambitions by expanding the IWT sector role in the container transport market on the Rhine (*Federal Ministry of Transport and Digital Infrastructure, 2016*; *Ministry of Infrastructure and Water Management, 2020*).

Furthermore, a shift from traditional bulk goods transport towards container transport has been recognized by individuals operating in the sector as an opportunity to improve the *viability* of the IWT sector (*LSP.1, SK.2, TAB.2*). Currently, bulk goods transport composes over 60% of freight transport shipped by the Dutch IWT sector (*Figee & Volker, 2015*). The demand for international bulk goods transport, however, has dropped by 19% in the last 5 years (*Statistics Netherlands, 2020c*), due to a decline in German heavy industry and Germany's transition away from coal-fuelled power (*Statistics Netherlands, 2020a*). This development is of importance to the Dutch IWT sector, as a majority of its bulk goods transport demand originates from Germany (*Statistics Netherlands, 2020c*). While bulk goods transport is expected to decline, growth in container transport demand is projected to endure as more *break bulk* is containerized, emerging markets in Africa and Asia are

[1] *Measured in tonne-kilometres transported over a year*

further integrated into the global transport network and container logistics in Europe becomes more established as more container terminals and warehouses are being built in the European hinterland (*Behdani, Wiegmans, Roso, & Haralambides, 2020*; *Haralambides, 2019*). Shifting towards container transport can therefore be seen as an opportunity to hedge against a possible further decrease in the demand for bulk goods transport in coming decades, thereby improving the viability of the IWT sector.

While long-term government transport planning ambitions combatting climate change and the viability of the IWT sector rely on the container modal shift from road transport toward IWT, this modal shift may be hindered by external[2] developments to the IWT infrastructure induced by climate change (*Meijeren, Groen, & Noordegraaf, 2011*).

In the previous two decades, a general decrease in Alpine meltwater and precipitation has led to an increased frequency of months with extremely low discharge and increased duration of periods of low discharge (*Ademmer, Jannsen, Kooths, & Mösle, 2019*; *Flörke et al., 2011*). Such a decrease in discharge reduces the river depth significantly and renders transporting freight on the Rhine less economical as *load factors* need to be reduced, increasing the energy consumption per tonne-kilometre shipped (*Flörke et al., 2011*; *Jonkeren, Rietveld, & van Ommeren, 2007*; *Rothstein & Scholten, 2014*). Climate projections estimate that discharge levels in the Rhine can on average possibly decrease by a further 27% during summer months (*Sperna-Weiland, Hegnauer, Bouaziz, & Beersma, 2015*) (*see Figure 1.2*). This would structurally expose the Rhine to extremely low discharges and reduce IWT's efficiency during LRD periods (see '*Climate Change*' on *page 37*), thereby hampering the modal shift ambitions (*European Commission, 2019*; *Figee & Volker, 2015*).

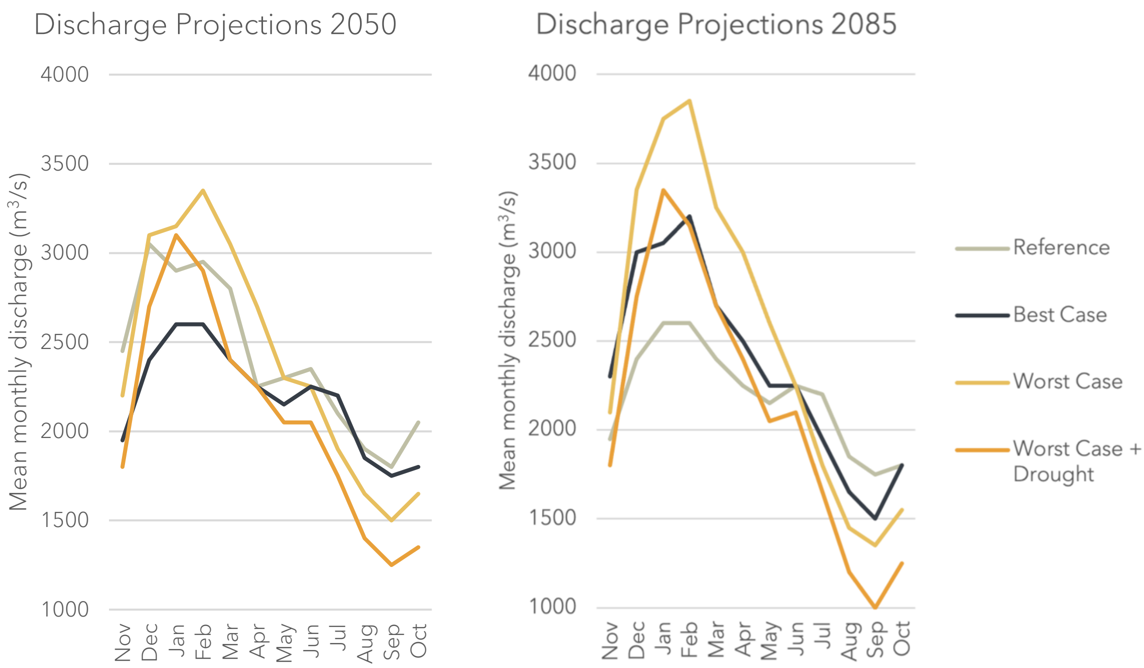

Figure 1.2 | KNMI's average monthly discharge projections at Lobith

[2] *Beyond the control of the stakeholders of the Dutch IWT sector*

in comparison to the current (reference) situation (Sperna-Weiland et al., 2015)

Although *low river depth* (*LRD*) periods on the Rhine can increase in intensity, duration and frequency in the coming decades, the IWT sector has previously been able to overcome severe and frequent LRD periods in the 1940s to 1970s (see *Figure 1.3*). A stable cost advantage over road transport has thus far recurringly led to the demand for IWT services returning once LRD periods have passed (*Jonkeren et al., 2007*).

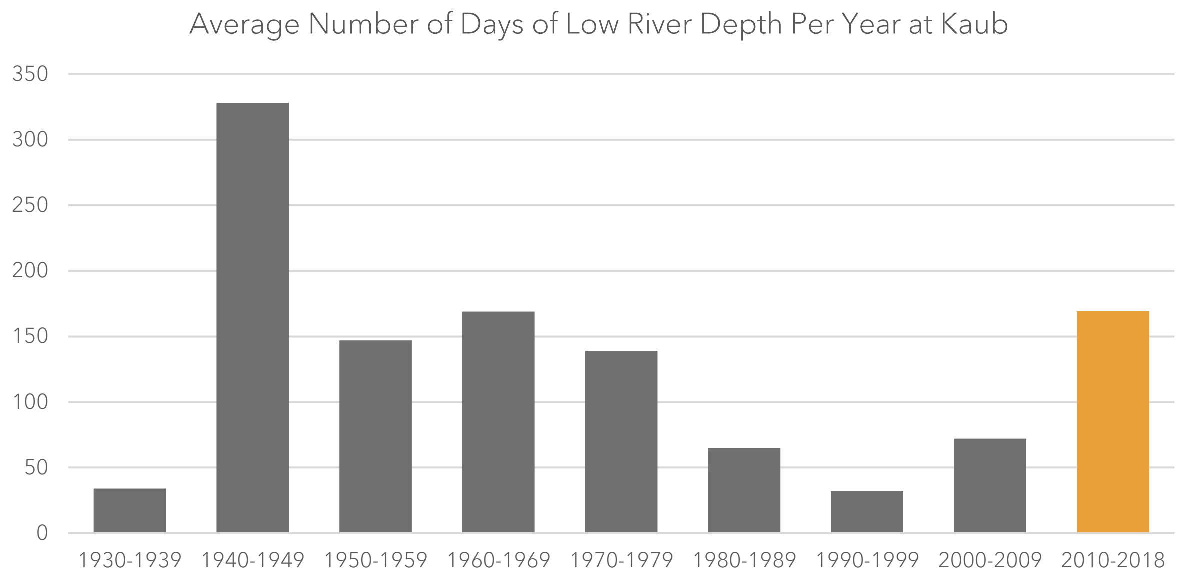

*Figure 1.3 | Average number of days of low river depth per year at Kaub From 1930-2018 (*Bundesanstalt für Gewässerkunde, 2019*)*

However, this cost-advantage may not be sufficient to stimulate the targeted modal shift in container transport (*Meijeren et al., 2011*). Historically, most of the demand for IWT services has been composed of demand for bulk goods transport, which is less time-sensitive than container transport and more suited to the economies of scale that characterizes IWT. However, if the IWT sector is to capture more of the container transport demand, IWT businesses (see *page 7*) will need to be able to satisfy heightened expectations for reliable on-time delivery that is common for road transport services (*Jonkeren, Jourquin, & Rietveld, 2011*). Shifting time-sensitive container transport from road transport to IWT requires that IWT businesses continue to fulfill container transport expectations during LRD periods. Deterioration of the *navigability* of the Rhine over the decades leading to the end of the century can lead to a decrease in IWT *competitiveness* against other modes of container transport (*Jonkeren et al., 2011*), ultimately making a shift to container transport harder and jeopardizing the long-term viability of the IWT sector. To an extent, this links the viability of the Dutch IWT sector to the viability of the Rhine as a navigable waterway, which underlines the need for climate change adaptation in the sector.

In sum, while the deterioration of the navigability of the Rhine can complicate European and Dutch modal shift ambitions (*Eng-Larsson & Kohn, 2012*; *Jonkeren et al., 2011*), it also has the effect of jeopardizing the viability of the Dutch IWT sector. A lack of competitiveness as result of a possible increase in the intensity, frequency, and duration of LRD periods on the Rhine added to a decline in traditional bulk goods transport demand threatens the viability of the IWT sector (see *Figure 1.4*). Implementing measures that adapt the Dutch IWT sector to future climate change scenarios could safeguard the long-term viability of the Dutch IWT sector, and by extension safeguard the Dutch government's transport policy ambitions.

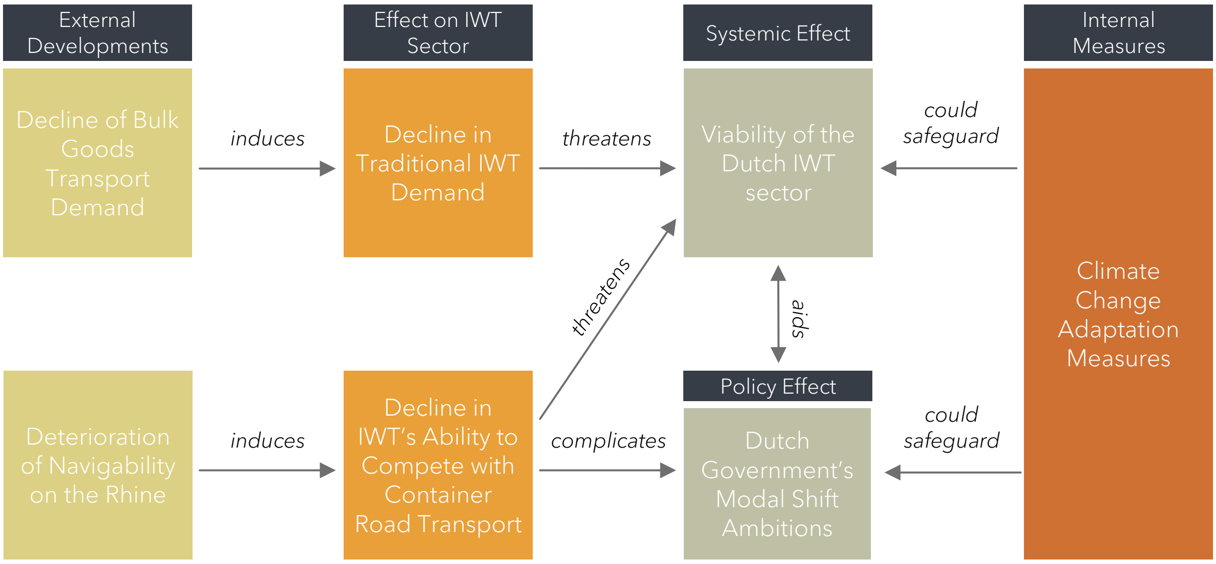

Figure 1.4 | Schematic overview of problem

1.2 Knowledge Gap

Currently, the viability of the Dutch IWT sector relies on IWT's persistent cost-advantage relative to road transport. A deterioration of the navigability of the Rhine can make competing with other modes of transport for shipper's transport demand to the European hinterland harder. Additionally, a decline in bulk goods transport demand could compel the Dutch IWT sector to shift towards servicing the more competitive container transport. These external developments lie beyond the direct control of individual IWT businesses and pose a risk to the Dutch IWT sector's long-term viability and the Dutch government's modal shift ambitions.

The exact timeline of how and the extent to which these external developments could take shape remains uncertain. Currently, IWT businesses acknowledge a need for climate adaptation measures, however, prolong the current situation in which no action towards climate adaptation is taken (*Centraal Overleg Vaarwegen, 2018*; *Ministry of Infrastructure and Water Management et al., 2019*). Most of the currently discussed measures that IWT businesses could take to adapt to potentially changing navigational conditions come with their trade-offs under different scenarios of the future navigability of the Rhine (*Riquelme-Solar, van Slobbe, & Werners, 2014*). A lack of evident optimal measures that would guarantee the long-term viability of an IWT business under any climate scenario could possibly form a reason for IWT businesses to be hesitant towards implementing climate adaptation measures.

Until now, studies have investigated the isolated effect of various external developments (i.e., climate change, transition to container transport, etc.) on the Dutch IWT sector (*Eng-Larsson & Kohn, 2012*; *Jonkeren, Rietveld, van Ommeren, & te Linde, 2014*). Other studies have explored the technical prospects of singular measures, such as building low *draught* barges (*van Dorsser, Vinke, Hekkenberg, & van Koningsveld, 2020*), conducting specific river training projects (*Havinga et al., 2006*) and implementing early warning systems for river depth (*Ionita & Nagavciuc, 2020*). Governments and think tanks have also made proposals on various measures IWT businesses can take (*Federal Ministry of Transport and Digital Infrastructure, 2019a*; *Krekt et al., 2011*; *Ministry of Infrastructure and Water Management et al., 2019*). However, few studies have focused on the overall long-term robustness of these internal[3] measures within in the context of the long-term viability of the IWT sector. A *robust decision analysis* approach to understanding the perspective of IWT businesses in the context of the future navigability of the Rhine has seen limited implementation in research (*van Dorsser, 2015*). While much academic literature has focused on the robust decision-making of governments with regards to infrastructural climate adaptation (*Ciullo, de Bruijn, Kwakkel, & Klijn, 2019*; *Groves, Molina-Perez, Bloom, & Fischbach, 2019*; *Hall et al., 2012*; *Middelkoop & Kwadijk, 2001*; *van Berchum, van Ledden, Timmermans, Kwakkel, & Jonkman, 2020*), the understanding of robust climate adaptation measures from the perspective of an IWT business is limited in academic literature.

Furthermore, most studies conduct analyses into isolated aspects of the IWT sector and leave the contribution of their analyses to the short-term decision-making of IWT businesses undiscussed. The input and feedback from stakeholders are commonly left out in these studies, which leaves the question on whether the insights have any potential in improving the decision-making of stakeholders with regards to the viability of their businesses.

An analysis of how the external developments and available internal measures interact with each could allow for IWT businesses to better evaluate the robustness of internal measures on the viability of the Dutch IWT sector. This could potentially empower IWT businesses to make robust decisions on investments and operations in the short term that benefit the long-term viability of the sector. Furthermore, a robust decision analysis approach performed with the input of experts and stakeholders throughout the sector may also provide IWT stakeholders a basis of concurred knowledge that can ease discussions between stakeholders.

[3] *Within the control of stakeholders of the Dutch IWT sector*

1.3 Research Objective and Specification

The main research objective of this thesis research project is to *explore the potential of a robust decision analysis approach to support IWT businesses make decisions on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector*. Following the lack of studies conducted on the robustness of internal climate adaptation measures, this thesis research project first performs a long-term robust decision analysis of various conceivable internal measures with the contributions provided by experts in the sector. The main objective of determining the analysis' contribution to IWT business decision-making is then pursued by presenting the analysis to IWT businesses. Ultimately, this thesis research project also aims to place the insights gained into the context of the Dutch government's modal shift ambitions.

Additionally, this thesis research project seeks to provide a basis for quantitative research into the robustness of internal climate adaptation measures on the viability of the IWT sector. Furthermore, this thesis research project can also point towards certain knowledge gaps where further quantitative research on the specific effects of certain external developments or internal measures can be of academic interest.

1.3.1 IWT Businesses as a Problem Owner

Before embarking on any analyses on the Dutch IWT sector, it is firstly practical to distinguish the entities that make up the sector. Although a strict demarcation of which entities belong to the Dutch IWT sector does not exist, this thesis research projects chooses to make such a demarcation that suits the research objective mentioned *above*.

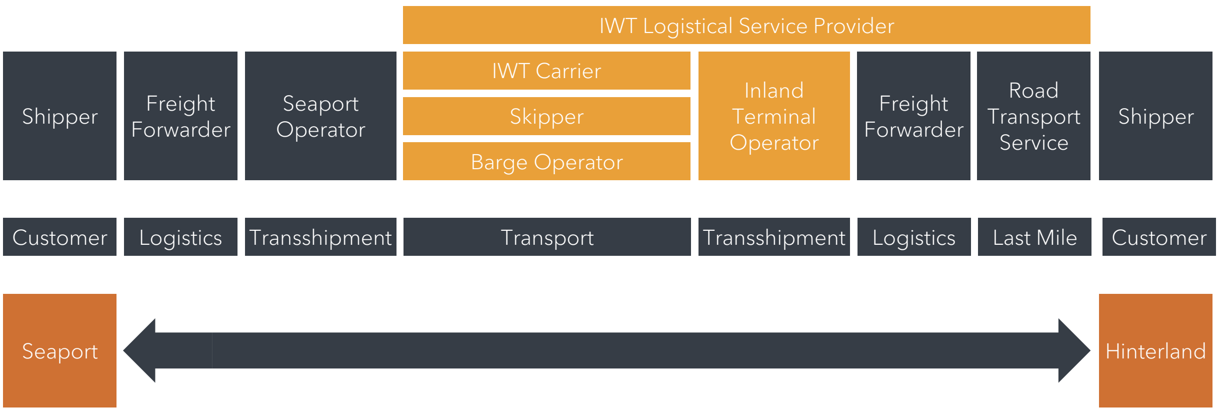

Figure 1.5 | Inland waterway transport sector supply chain entities and their respective supply chain activities (Yellow: problem owners; Blue: other stakeholders) (Oelfke & Oelfke, 2003)*(for individual definitions see glossary) (for Dutch and German versions see page 99)*

The viability of the Dutch IWT sector is not an interest that can be ascribed to a single entity, rather it can be defined as a collective interest that can be attributed to the entities that operate in it and use its services. This includes the various Dutch seaports (e.g., the Port of Rotterdam), shippers in the various *Rhine riparian states*, *freight forwarders*, IWT logistical service providers, *skippers*, IWT carriers, barge operators, and inland terminal operators. It also includes the Dutch and German governments who support the viability of the IWT sector with the aim of providing efficient transport between industries, creating jobs, and increasing geo-political strength. While each of these stakeholders have an interest in the Dutch IWT sector, not all stakeholders are fully dependent on its long-term viability. The distinction between stakeholders who are fully dependent on the viability of the IWT sector and stakeholders who merely have a strong interest in the Dutch IWT sector results in two clusters of stakeholders that can be summed up as: IWT businesses whose business model is mostly located within the IWT sector and parties that make use of IWT logistical services or the services the sector enables (see *Figure 1.5*).

Problem Owners *dependent on IWT*	Other Stakeholders *independent of IWT*
IWT Logistical Service Providers	Dutch Seaports
Skippers	Shippers
IWT Carriers	Freight Forwarders
Barge Operators	Dutch & German Government
Terminal Operators	

Figure 1.6 | Problem owners and stakeholders

While the latter cluster is considered as a group of stakeholders within this thesis research project, it is regarded as a subset that form the problem owners within the analysis of this thesis research project (i.e., the entity or entities concerned with the problem at hand). While having a vested interest in the viability of the Dutch IWT sector, independent stakeholders only value the viability of the Dutch IWT sector as a means to another end (e.g., goods transport service, climate agenda), while the cluster of parties that carry out IWT logistical services pursue the viability of the Dutch IWT sector as an end on its own. A shipper, for instance, could prefer to use the IWT services for because of its affordability and reliability, but can ultimately choose to use a different mode of transport if the benefits of using IWT services diminishes in relation to using other modes of transport. This is not only a hypothetical phenomenon, as many of the shippers who shifted their shipments from IWT onto other modes of transport during the extreme LRD period in 2018 have not returned to the IWT sector until today (*LSP.1, LSP.2*). Due to their ability to use other modes of transport, shippers are not as interested in the long-term viability of the IWT sector as the businesses that provide the IWT services.

Meanwhile, businesses who provide IWT services are more invested in the IWT sector. If the IWT sector becomes less competitive with respect to other modes of transport, IWT businesses will suffer losses in demand for its services. IWT businesses therefore have a self-serving interest in the long-term viability of the IWT sector. This thesis research project, therefore, considers the IWT businesses to be problem owners (see *Figure 1.6*). The robust decision analysis conducted in this thesis research project is produced from the perspective of the problem owners.

1.3.2 Problem Demarcation

As is common practice for policy analytical research (*Thissen & Twaalfhoven, 2001*), the research activity for this thesis research project is demarcated along two significant dimensions: subject matter and time.

Whereas LRD periods can occur in the Netherlands, due to the differences in *river morphology* and hydrology, the intensity, frequency, and duration of LRD periods are more pronounced in the German parts the Rhine. This can lead to instances in which river depth levels at the Dutch entry point of the Rhine at Lobith are recorded at 2.44 meters while river depth at Kaub in Germany only rises to 1.74 meters and 2.18 meters in Cologne (*ELWIS, 2015*). Furthermore, while the Dutch IWT sector mainly operates in the Netherlands, a significant segment of the Dutch IWT sector (~45%) conducts transport services that cross international borders to other Rhine riparian states (*Statistics Netherlands, 2020b*). The significance of the international business operations to the Dutch IWT sector and the fact that the intensity, frequency, and duration of LRD periods are higher in Germany provides justification for the subject matter demarcation to include IWT that navigates all sections of the Rhine.

Figure 1.7 | Map of Rotterdam-Basel navigation corridor

Although the Rhine officially splits into three branches (Waal, IJssel and Lek) upon entering the Netherlands, this thesis research project only considers IWT on the Waal in addition to the IWT that operates on the Rhine. While LRD can occur on other parts of the Dutch IWT system, only the Waal does not contain any river control mechanisms (e.g., weirs, locks, etc.). This limits the capacity to apply infrastructural measures and makes IWT on the Waal an interesting case to study. Furthermore, the Waal services most international IWT. A part of the Rotterdam-Basel corridor the Waal offers an unhindered connection between the Port of Rotterdam and inland ports along the Rhine (see *Figure 1.7*). Considering that this thesis research project focuses on IWT that crosses international borders, only IWT activity on the Waal and Rhine are studied as part of this thesis research project.

The temporal demarcation of this thesis research project can be set to fit the long-term outlook on the long-term viability of the Dutch IWT sector. While LRD periods occur regularly throughout history, climate change can increase the intensity, frequency, and duration of these periods. Most projections for these changes range from 30-50 years (*Sperna-Weiland et al., 2015*). Moreover, the decision-making within the IWT sector is characterized by the typical depreciation time of most assets (i.e., barges), which does not exceed 50 years (*TAB.2*). This thesis research project, therefore, demarcates the problem from the near future to the next 50 years.

1.4 Research Approach

To establish whether a robust decision analysis approach has any potential in supporting IWT businesses make decisions on climate adaptation measures that could improve the long-term viability of the Dutch IWT sector, this thesis research project chooses to work together with IWT stakeholders. The lack of previous robust decision analytic research on the IWT sector requires this thesis research project to conduct its own robust decision analysis. The initial research activities are, therefore, focused on analyzing the various components that make up the Dutch IWT system. Consequently, this thesis research projects uses a framework for conducting robust decision analyses, developed by *Lempert, Popper, and Bankes (2003)*. Their "*XLRM framework*" can be used to analyze the robustness of measures under various permutations of future scenarios *(Lempert et al., 2003)*. As the framework employs a systematic classification of four elements (external developments (X), internal measures (L), relations (R), and objectives (M)) (see '*Robust Decision Analysis*' on *page 14*) to guide robust decision analyses, this thesis research project structures the research activities involved in its robust decision analysis along the same four elements.

As follows, this thesis research project commences with an analysis into what the long-term viability of the Dutch IWT sector entails. This analysis is directed at understanding which characteristics of IWT set it apart as a mode of transport and allows it to compete with other modes of transport. These characteristics form the collection of objectives (M) for IWT businesses to maintain and improve upon to safeguard the long-term viability of the Dutch IWT sector. Interviews with IWT businesses provide the insights on the objectives of the Dutch IWT sector.

Following an establishment of the objectives of the Dutch IWT sector with regards to its long-term viability, an analysis into the external developments (X) with regards to the future navigability of the Rhine is conducted. The *XLRM framework* characterizes the external developments to be trends that are beyond the control of the problem owner(s). These external developments are often characterized by a range of uncertainty. An extensive desk research phase is intended to provide a broad understanding of the uncertain external developments affecting the Dutch IWT sector, while a brief round of interviews seeks to reaffirm the insights from the desk research.

A third phase of this thesis research project is aimed at creating a list of potential internal measures (L) that can be applied to the Dutch IWT sector. These measures are defined to be any action, whether it be technical, managerial, logistical, etc., that IWT businesses can take to adapt to changes in future navigability of the Rhine induced by climate change. This phase predominately encompasses interviewing a broad selection of stakeholders of the Dutch IWT sector on their perspective towards preparing the sector for the previously acknowledged external uncertainties.

Once information has been established on the objectives, external developments, and internal measures, a fourth phase of this research is meant to relate (R) these three elements to each other within a systems diagram. This diagram showcases how the external developments and internal measures influence the targeted objectives. By creating various scenarios of how external developments can unfold in the future, a robust decision analysis can use the systems diagram to provide conclusions on the robustness of the internal measures.

Ultimately, this thesis research project intends to understand how the robust decision analysis that is produced following the previous phases could support IWT businesses in their decision-making on climate adaptation measures that could improve the long-term viability of the Dutch IWT sector. A series of evaluation interviews provide the feedback from stakeholders on how they could use robust decision analysis as part of their decision-making process.

1.4.1 Research Questions

As this thesis research project delves into the issue of the Dutch IWT sector's long-term viability, a main research question provides a concrete indication of which knowledge gap is intended to be answered by this thesis research project. As previously mentioned, this thesis research project is centred on exploring the potential of a robust decision analysis in supporting IWT businesses make decisions on climate adaptation measures that could improve the long-term viability of the Dutch IWT sector. The main research question (MQ) of this thesis research project can therefore be formulated as the following:

MQ

What is the potential of a robust decision analysis in supporting IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector?

An additional series of sub-questions (SQs) further specifies the direction of this thesis research project. To maintain a methodical organization, the format of the sub-questions is outlined within the XLRM framework and correspond to the five phases mentioned *above*. In total, five sub-questions help guide the research activities and can be outlined as follows:

SQs

SQ 1 *What does the long-term viability of the Dutch IWT sector entail? (M)*

SQ 2 *What are the external developments affecting the long-term viability of the Dutch IWT sector? (X)*

SQ 3 *What internal climate change adaptation measures could safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (L)*

SQ 4 *What internal climate adaptation measures can robustly safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (R)*

SQ 5 *What is the potential of the robust decision analysis generated as a product of answering SQs 1 through 4 in supporting the IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector?*

1.4.2 Research Structure

For the purpose of creating some overview, the table *below* displays a chapter outline of this thesis research report in relation to the research approach and the research sub-questions detailed in the section *above*.

Each of the five previously discussed research sub-question is addressed in a dedicated chapter. Preceding these five chapters, two chapters introduce the research problem and the methods used. Two final chapters are devoted to the discussion of the implications and limitations of this research and a conclusion on the main findings with regards to the main research question.

Table 1.1 | Chapter Outline

CHAPTER		OBJECTIVE	SUB-QUESTIONS
1	Introduction	Introduce the problem, research objective, research approach and relevance	
2	Methods	Announce the methods used in the research	
3	Viability as an Objective	Define the objective of long-term viability of the Dutch IWT sector	SQ 1
4	External Developments	Understand the external developments that affect the long-term viability of the Dutch IWT sector	SQ 2
5	Internal Measures	Construct an inventory of internal climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector	SQ 3
6	Analysis	Explore the robustness of internal measures on safeguarding the long-term viability of the Dutch IWT sector in the context on the external developments	SQ 4
7	Evaluation	Evaluate the robust decision analysis conducted with stakeholders of the Dutch IWT sector	SQ 5
8	Discussion	Discuss the implications and limitations of the results	
9	Conclusion	Present conclusions	MQ

2 Methods

While *Chapter 1* discussed this thesis research project's content, this chapter aims to provide an overview of the tools and methods used throughout the thesis research project. Due to the scattered use of different methods, an overview serves to summarize the link between the methods and the research sub-questions. This includes an explanation on what methods were used, why they were used and when they were used.

2.1 Robust Decision Analysis

The XLRM framework, developed by *Lempert et al. (2003)*, offers a method to analyze problems that are characterized by long-term deep uncertainty (*van Dorsser, Walker, Taneja, & Marchau, 2018*). It enables policy analysts to study the behaviour of a system under different scenarios in the unfolding of external developments (*Kwakkel, 2017*; *van Dorsser et al., 2018*). Policy analysists can then learn how policies can be robustly designed to safeguard the interest in the system under these scenarios. This makes the XLRM framework suitable for *robust decision analysis*, in which the objective is to evaluate the robustness of decisions (i.e., measures) under a wide range of future scenarios, rather than searching for optimal performing decisions under one (most likely) scenario *(Walker, 2000)*. Previously, *van Dorsser (2015)* has used the XLRM framework for analyzing the robustness of long-term government policies aimed at the IWT sector and has deemed it valid for other analyses of the IWT sector. By applying the XLRM framework, this thesis research project aims to produce a robust decision analysis that shows how certain internal measures can robustly safeguard the long-term viability of the Dutch sector against variations in external developments.

The *XLRM framework* allows models of a given system of interest to be classified into four elements: external developments (X), internal measures (L), relationships (R), and objectives (M) in a model (*Lempert et al., 2003*) (see *Table 2.1*). This results in a model that contains two types of input (external developments and internal measures) and one type of output (objectives). The links between the inputs and output are considered the relations (R).

Table 2.1 | XLRM Elements as Described by *Lempert et al. (2003)*

ABB.	ELEMENT
X	External developments are factors outside the control of decision-makers that may nonetheless prove important in determining the success of any internal measures taken
L	Internal measures are near-term actions that, in various combinations, comprise the strategies decision-makers want to explore
R	Relations are potential ways in which the future of a given system evolves over time based on the manifestation of external developments and internal measures
M	Objectives are the performance standards that stakeholders would use to rank the desirability of various future outcomes

The XLRM framework uses this classification of system elements to isolate any uncertain factors from the system of interest and deeming them external to the system (*Kwakkel, 2017*). Policy analysts can then use these uncertain external factors to identify potential vulnerabilities of proposed measures. In an iterative process, vulnerable measures can be altered to become more robust to possible uncertain external factors (*Groves & Lempert, 2007*; *Lempert, Groves, Popper, & Bankes, 2006*). The objective when using the XLRM framework is therefore to identify a series of measures that are robust against the long-term development of certain external developments (*Groves & Lempert, 2007*).

While *Lempert et al. (2003)* propose that the XLRM framework be used in the context of decision-making under deep uncertainty to provide quantitative analysis on robust decision-making, this thesis research project uses the framework to produce qualitative insights on measure robustness. While most studies on robust decision-making use the XLRM framework as a means of quantitative exploration of robust measures (*Ciullo et al., 2019*; *Haasnoot et al., 2014*; *Kwakkel & Haasnoot, 2012*; *Kwakkel, Walker, & Marchau, 2010*; *Lempert et al., 2006*; *van Berchum et al., 2020*), this thesis research project focuses on the XLRM framework's potential in communicating to stakeholders in the Dutch IWT sector how they could understand the trade-offs between robust measures. Rather than using the framework as "a tool for producing landscapes of plausible futures of the high-dimensional decision spaces" (*Lempert et al., 2003, p. xvi*), this thesis research project uses the framework as a tool to communicate the effectiveness of certain internal measures under a smaller set of uncertain external developments with stakeholders. Whereas *Lempert et al. (2003)* propose the use of a large ensemble of scenarios to quantitatively provide insights into the robustness of measures, this thesis research projects only uses several key drivers (i.e., external developments) and qualitatively researches their systemic effect in combination with certain internal measures to convey simple trade-offs between robust measures. Naturally, using the XLRM framework in this thesis research project allows and possibly provides encouragement for further studies to intuitively build on this study and perform quantitative robust decision analysis.

The XLRM framework's value as an organizational and communicative tool has been eluded to by *Lempert et al. (2003)*. The XLRM framework is meant to guide the robust decision analysis by providing a simple way of relating the various elements to each other. The use of four elements to describe a system allows for the organization of relevant information to the problem and facilitates the explanation to a broader public as it generates a clear overview of the problem (*Lempert et al., 2003*). The framework can therefore on the one hand be used as a method for analyzing the robustness of certain measures, while on the other hand be used as a method to convey the results of a robust decision analysis effectively to stakeholders.

A figure *below* portrays a systems diagram that is fitted towards the XLRM framework and adapted towards the terminology used in this thesis research project. It shows how the XLRM framework considers external developments and internal measures factors can be considered inputs that affect the relations within the system of the IWT sector. Their interaction results in an effect on the objectives of the Dutch IWT sector. This visual depiction of the XLRM framework (i.e., the organization, terminology, and colour scheme) is used throughout this report and during communication with stakeholders during the validation process.

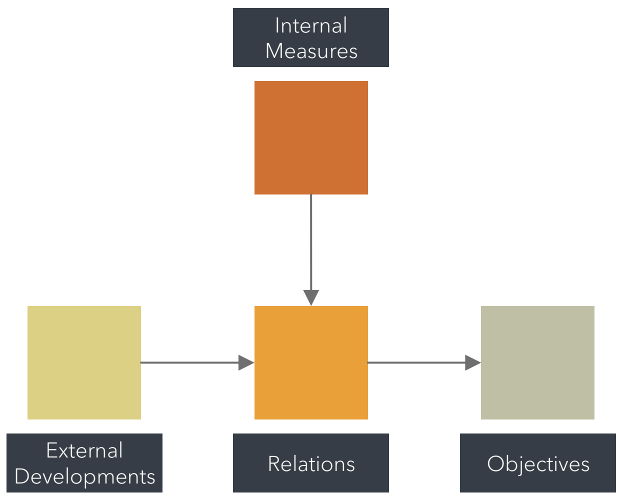

Figure 2.1 | XLRM framework as graphically portrayed in this thesis research project (adapted from (Lempert et al., 2003)*)*

2.2 Data Gathering

To conduct a robust decision analysis, this thesis research first leads an extensive data gathering phase to provide a solid scientific basis for the information portrayed in the robust decision analysis. Furthermore, as the robust decision analysis is intended to be of use to stakeholders in the Dutch IWT sector, this thesis research project also adds the input from experts in the sector. This should allow stakeholders to add their knowledge to and verify any information that has not been elaborately discussed in scientific literature or official publications.

A preliminary round of literature research provides an initial basis of information on the external developments, internal measures, and objectives in the context of the long-term viability of the Dutch IWT sector, while further rounds of interviews with stakeholders serve to validate certain insights gathered from the previous round of desk research and deepen the pool of researched information. These interviews are further intended to gather an understanding of the relations between the external developments and internal measures. Often these relations are not described in scientific literature as this knowledge is mostly of interest to stakeholders of the Dutch IWT sector.

2.2.1 Desk Study

Due to the complexity and extent of the problem of long-term viability of the Dutch IWT sector, a large amount of time is spent on an extensive desk study phase that allows for the acquisition of knowledge on the exact challenges at hand and the development of a broad understanding of the workings of the sector.

Furthermore, the desk study phase also points towards areas where knowledge is still needed. This allows for a more accurate selection of expert participants to interview and enhances the precision of interrogation during the interviews. The desk research phase can therefore be seen as catalyst in the data gathering phase of this thesis research project that provides a sufficient level of understanding to prepare for the interviewing of experts.

To illustrate how the process of the desk study is conducted, this subsection presents a description of how keywords are selected to search for relevant literature on the Dutch IWT sector. Scientific literature on robust decision analysis was found by leafing through catalogues of literature provided in Engineering and Policy Analysis Master programme and the Technology, Policy, and Management Bachelor's programme and selecting relevant literature. Ultimately, a summary of the literature used in this thesis research project is given at the end of this subchapter.

<u>Selection of Keywords</u>

Finding relevant literature on the Dutch IWT sector during a desk study is a process done by trial-and-error. By starting with a few general keywords (e.g., "inland shipping", "low river depth", etc.) and slowly accumulating more keywords from the research papers read, it becomes possible to generate an extensive dictionary of keywords/search terms. These keywords serve as a database for finding literature via research search engines such as Scopus and Google Scholar. A selection of the most relevant keywords is presented *below*. The table categorizes the keywords into the three elements of the XLRM framework that were research within the desk study.

Within the search queries, most of the keywords below were accompanied by search terms such as Rhine, Inland, Waterway or Navigat*, etc. to narrow down the search results to the topics relevant to this thesis research project.

Table 2.2 | Research Keywords Used in Desk Study

EXTERNAL DEVELOPMENTS (X)	INTERNAL MEASURES (L)	OBJECTIVES (M)
Precipitat*	Draught	Robustness
"Climate Change"	Infrastruc*	Reliability
Emission	Digital*	Efficiency
"Transport Costs"	Network*	Economy
"River Training"	Intermodal*	Sector
Erosion	Synchromodal*	Ship*
"Low water"	"Early Warning"	Competit*
Morphology	Predict*	Viab*
	"Depth Measure*"	"Business Model"

Literature Review

To grow a list of relevant literature on the Dutch IWT sector, a process of "snowballing" is used in which searching with a set of initial keywords leads to a variety of relevant literature, which in turn reference related literature or provide new information for new keywords that can be used as search terms. Following the referenced literature or searching with the newfound keywords allows for the formation of a growing library of relevant literature. Ultimately, the desk study yields a collection of relevant peer-reviewed research papers and other sources such as news articles, government agency reports, web pages, and conference papers.

A selection of the main scientific literature and official publications used as part of this thesis project that discuss the basis of the knowledge on the external developments, internal measures, and objectives in the Dutch IWT sector is listed in *Table 2.3*.

Table 2.3 | Literature Review on IWT Sector

CITATION	(X)	(L)	(M)
(*Ademmer et al., 2019*)	X		
(*Wiegmans & Konings, 2015*)			X
(*Blaauw, 2009*)		X	
(*Eng-Larsson & Kohn, 2012*)		X	
(*Hakstege, 2013*)	X		
(*Havinga, 2020*)	X		
(*Jonkeren et al., 2007*)		X	
(*Jonkeren et al., 2014*)	X		
(*Kempmann & Roux, 2020*)		X	
(*Koolwijk, 1992*)	X		
(*Krekt et al., 2011*)		X	
(*Meijeren et al., 2011*)			X
(*Middelkoop et al., 2001*)	X		
(*Riquelme Solar, 2012*)	X	X	
(*Riquelme-Solar et al., 2014*)		X	
(*Stopford, 2008*)			X
(*van Dorsser, 2015*)			X
(*World Weather Attribution, 2018*)	X		
(*Spreafico & Lehmann, 2009*)	X		

(*Hooke, 2016*)	X	
(*Meijeren et al., 2011*)	X	X
(*Magretta, 2002*)		X
(*Sys & Hellebosch, 2021*)	X	X
(*de Lima, Trentin, Oliveira, Batistus, & Setti, 2015*)		X

A selection of the scientific literature that is formative to the robust decision analysis conducted as part of this thesis research project is presented in the table *below*.

Table 2.4 | Literature Review on Policy Analysis

CITATION	SYSTEMS DIAGRAMMING	XLRM FRAMEWORK	ANALYSIS VALIDATION
(*Groves & Lempert, 2007*)		X	
(*Haasnoot et al., 2014*)		X	
(*Haraldsson & Sverdrup, 2013*)	X		
(*Howard & Matheson, 2005*)	X		
(*Kwakkel & Haasnoot, 2012*)		X	
(*Kwakkel et al., 2010*)		X	
(*Kwakkel, 2017*)		X	
(*Lane, 2000*)	X		
(*Lempert et al., 2003*)		X	
(*Lempert et al., 2006*)		X	
(*Morecroft, 1982*)	X		
(*Quade, 1980*)	X		
(*Sage & Olson, 2001*)	X		
(*Sage, 1992*)	X		
(*Thissen & Twaalfhoven, 2001*)			X
(*van der Lei, Enserink, Thissen, & Bekebrede, 2011*)	X		
(*van Dorsser et al., 2018*)		X	
(*van Dorsser, 2015*)		X	
(*Walker, 2000*)		X	

2.2.2 Interviews

This thesis research project employs information from interviews from 17 different stakeholders of and (academic) experts on the Dutch IWT sector as a key source of information. While an extensive round of desk research provides a general understanding for the problem, it is not able to capture the subjective consideration between interests accurately and is limited in its ability to give an accurate representation of the dependencies in the system that are felt when working in the field. Although studying literature can result in a list of various external developments that theoretically affect the Dutch IWT sector, it cannot place these developments in context of the extent to which they threaten stakeholders of the Dutch IWT sector. Furthermore, as is pointed out in the '*Knowledge Gap*' on *page 5*, not all relations between the external developments, internal measures and their effects on the IWT sector have been studied thoroughly within scientific literature. This compels the need to go beyond a desk study in pursuit of gathering sufficient information to produce a robust decision analysis that meets the demands of stakeholders in the field.

Information provided by stakeholders of the Dutch IWT sector would complement the knowledge gained during the desk study. Stakeholders hold valuable qualitative information on their experiences and beliefs with regards to the external developments affecting the Dutch IWT sector and have a vast amount of knowledge on the most recent internal measures discussed within and around the IWT sector. Presenting the findings from the desk study to stakeholders can spark conversations on their subjective experiences. Tapping into this source of information can generate further understanding of new links between the external developments and internal measures and their effects on the IWT sector that have not been studied before.

Furthermore, this thesis research project intends to provide stakeholders and decision-makers in the IWT sector a tool to understand how to safeguard their long-term viability. The personal contribution of stakeholder information to the forming of the tool ensures that the tool is shaped to benefit them.

Interview Method

To gather this information from stakeholders and (academic) experts, a method needs to be developed that suits the stakeholder and stimulates conversations that produce noteworthy information. Often the most interesting information on stakeholders' subjective experiences and beliefs is preferred to be kept confidential as it contains information on an organization's strategies and personal opinions. This requires a setting that makes stakeholders comfortable to share their personal experiences and beliefs with regards to how external developments may influence them and what they believe are measures that need to be taken by them or others.

Semi-structured or semi-standardized interviews with stakeholders suit this objective well and are commonly used as a data collection tool in qualitative research that in which participants are known for having varying subjective views (*Ryan, Coughlan, & Cronin, 2009*; *Tod, 2006*). By conducting one-to-one interviews and asking open-ended questions, based on the principle of allowing the interview to tell his or her own story, it becomes possible to explore the individual perspective of a stakeholder. *Ryan et al. (2009)* call this approach discovery interviews. Often, individuals in the IWT sector are less acquainted with academic interviews and have a preference towards holding an ordinary conversation. Discovery interviews therefore suit their preference for open discussion. However, in contrast to unstructured interviews, semi-structured interviews still have prepared questions and are conducted along a framework of guiding topics that are addressed one by one (*Bridges, Gray, Box, & Machin, 2008*). This allows for the balance between giving interviewees the freedom to express themselves and being able to hold interviewees to a specific agenda and retrieve information pertinent to the research objective. The interviews conducted as part of thesis research project is therefore guided by a series of open-ended questions that can be altered in their sentencing and order of interrogation depending on the interview.

Additionally, the technical vernacular used by the sector need to be accounted for when approaching stakeholders to accommodate a productive conversation. During the desk study conducted prior to interviewing stakeholders, a list of technical vernaculars is assembled in the various languages (Dutch and German) in which the interviews are to be held (see *glossary* on *page 86*). This list is studied and rehearsed before the interview are held to ensure conversations can be held at an expert level.

Furthermore, additional issues such as the busy time schedules of stakeholders needed to be accompanied when conducting interviews. This fact, coupled with the constraints on personal distance induced by the COVID-19 pandemic, resulted in most interviews being held for no more than 45 minutes and being conducted virtually via video conferencing software.

In addition to the interviews that are to be held via video conferencing software, in-person interviews with skippers are to be conducted as these can be combined with in-field research (see '*Process of Validation'* on *page 30*). In-field research offers a unique opportunity to gain tacit knowledge on the decision-making of an IWT business. This in-field research is to be conducted during two separate multi-day physical visitations on barges operating between Dutch seaports and the German hinterland. Although this knowledge is not easily quantifiable, it is intended to add to the overall implicit knowledge of the researcher and enable better consideration of which aspects should be included in the robust decision analysis. The value of these experiences is not to be underestimated as the knowledge that would otherwise be gained through interviews is now more effectively experienced first-hand. Ultimately, in-person experience allows the researcher to better integrate the perspective of an IWT business into the robust decision analysis. All health protocols were taken to responsibly protect the safety of the interviewer and the interview participants during the COVID-19 pandemic.

<u>Objectives of Conducting Interviews</u>

Whereas the process of conducting interviews generally serves the expansion and validation of knowledge on the various elements of the IWT system in accordance with the XLRM framework, not every interview has the identical objective. The different data gathering objectives that interviews aim to fulfill can loosely be divided into four objectives that mirror the four elements of the XLRM framework and interviews that function as validatory interviews that seek to gather the stakeholder reactions to the produced robust decision analysis (see table *below*).

While some interview participants are to be approached purely for their objective expertise on the Dutch IWT sector in context of deteriorating navigation conditions (e.g., academics), others are intended to also share their subjective experiences with regards to question of the long-term viability of the Dutch IWT sector. Each objective invokes a specific cluster of participants to interview who can provide information catered to the objective.

Table 2.5 | Objectives of Conducting Interviews

ELEMENT	OBJECTIVE	PARTICIPANTS
X	Confirm or disprove information on external developments found during desk	Stakeholders, Academics
L	Assemble a list of different internal measures	Stakeholders
R	Link external developments and internal measures to their effect on the Dutch IWT sector	Stakeholders
M	Identify the objectives of the IWT sector with regards to its long-term viability	Problem Owners[4]
	Validate the produced robust decision analysis and explore the potential it has to support IWT businesses' decision-making	Problem Owners

<u>Selection of Interview Participants</u>

As interviews constitute a major source of data for this thesis research project, it is important to select interview participants purposefully and accurately. Interview participants are selected with respect to each of the five objectives listed *above*. Furthermore, the selection of interview participants is sought to be specifically catered to the problem being analyzed on the one hand, while on the other hand also being diverse in the perspectives it encompasses. To make sure that the pool of participants is neither cast too wide nor too narrow, a thorough selection procedure is conducted. Three selection procedures form a method that allows for the creation of an initial list individuals and organizations and that functions as a verification mechanism that ensures participants suit this thesis research

[4] *For definition of problem owners see 'IWT Businesses as a Problem Owner' on page 7*

project's objective before being selected. These procedures are explained in the following paragraphs.

Firstly, a participant's potential contribution to the individual objectives is examined.

Table 2.5 shows which cluster(s) of participants are intended to be interviewed to fulfill which of the four research objectives. *Figure 1.6* shows which organizations and individuals are considered 'Problem Owners' and which are considered 'Stakeholders' (note that 'Problem Owners' are also 'Stakeholders'). Academics are a cluster composed of various individuals that have academic knowledge of the IWT sector and its challenges, however, do not actively pursue interests in the sector and are therefore not considered stakeholders.

Within this procedure, the set of interview participant stakeholders is selected to represent a diverse range of stakeholders. While some overlap in stakeholder representation is necessary to filter out biased information from single participants, a diverse set of stakeholders brings across a diverse perspective that serves as the basis of a robust decision analysis that is then most likely able to accommodate the most IWT businesses.

The second procedure is used to verify that participants are representative of the research topic. As mentioned in the '*Problem Demarcation*', this thesis research projects intends to research the IWT sector that operates between the Waal and Rhine. Furthermore, participants should be affected by LRD periods to a certain extent to be considered a stakeholder of the Dutch IWT sector's long-term viability with regards to the future navigability of the Rhine. Lastly, a participant's diversification of modes of transport is interesting to note, as stakeholders who are diversified depend less on the IWT as means of transport. These three points of interest form the three criteria that participants are graded on (see table *below*). The suitability of a participant towards the research topic can vary, but participants should at least adhere to the criteria to a certain degree.

Table 2.6 | Participant Selection Criteria

CRITERIA	
1	Involvement in activities of freight transport over the Waal and Rhine between seaports in the Netherlands (e.g., Port of Rotterdam) and clientele in Germany
2	Vulnerability of business operations towards LRD periods
3	Concentration of shipping activity in IWT

A final procedure uses a set of classifiers to ensure that the pool of selected participants is to an extent representative of the group of problem owners and stakeholders addressed in this thesis research project. To uphold the diversity of the participant pool, participants with different characteristics should be chosen. This ultimately leads to a participant pool that spans the group of problem owners and stakeholders. To keep track of the characteristics of participants, each participant is sorted in four classification categories (see table *below*). Each classification category is composed of different classifiers. For each classification category, it is intended that at least one participant represents each classifier to ensure representativeness. To clarify, the pool of participants should be composed of participants that operate in all supply chain segments (e.g., *shippers*, logistical service providers, infrastructure operators, freelance skippers, etc.) and have varying degrees vertical integration of assets (e.g., terminals, vessels, etc.). Both Dutch and German participants should be represented in the participant pool, as Dutch and German stakeholders of the Dutch IWT sector may hold varying perspectives. Lastly, this procedure intends to verify that the specialization in type of freight (e.g., bulk goods, containers, etc.) transported is also diverse, as stakeholders transporting different types of freight experience the external developments differently and thus may have varying perspectives. Checking for these classifiers helps ensure representativeness within the participant pool.

Table 2.7 | Participant Classification Categories

CLASSIFICATION CATEGORIES	CLASSIFIERS
Supply chain segment of main operations	shippers, logistical service providers, infrastructure operators and freelance skippers
Vertical integration of assets	terminals and vessels
Geographical location of main operations	Netherlands and Germany
Specialization in type of freight transported	containers and bulk

The three selection procedures are initially employed to gauge which individuals and organizations should be approached. A general search via Google for participants provides an initial list of conceivable participants that are catered to each objective, meet the various criteria, and fit into each classification category. By consulting the contact pages of organizations or the LinkedIn pages of individuals, direct contact can be made with individuals to request their participation in an interview. While conducting the interviews with these participants, it becomes possible to ask whether they can refer to any individuals that have a stake in the Dutch IWT sector. Before a participant is chosen, he or she is first verified through the selection procedures to ensure representativeness and suitability to the research topic. This technique uses the professional networks of the earlier participants and allows for the growth of a pool of participants.

2.2.3 Data Handling

As part of this thesis research project, data is collected, processed, and published. How this data is handled is an ethical matter as it contains personal data.

The collection of data from private citizens is a task that requires due diligence on the part of respecting the privacy of all interview participants. During open dialogue and spontaneous discussion with participants, sensitive and personal information can be exchanged, which is not intended to be released to the public (even for the purposes of academic research). This information cannot be released and must be handled diligently. This is not only done to stimulate participants to speak freely, but also to uphold the ethical integrity of this thesis.

This thesis research project goes through the necessary effort to process personal data securely. All procedures with regards to data collection, processing and storage have been discussed with a data steward of the Delft University of Technology and approved by the university's Human Research Ethics Committee.

Before conducting interviews with participants, participants were explained their rights and freedoms during the interview and were made aware of the purpose of the interview. Each participant signed a consent form at the end of the interview, disclosing that they had indeed been made aware of all matters concerning data collection, processing, and publication.

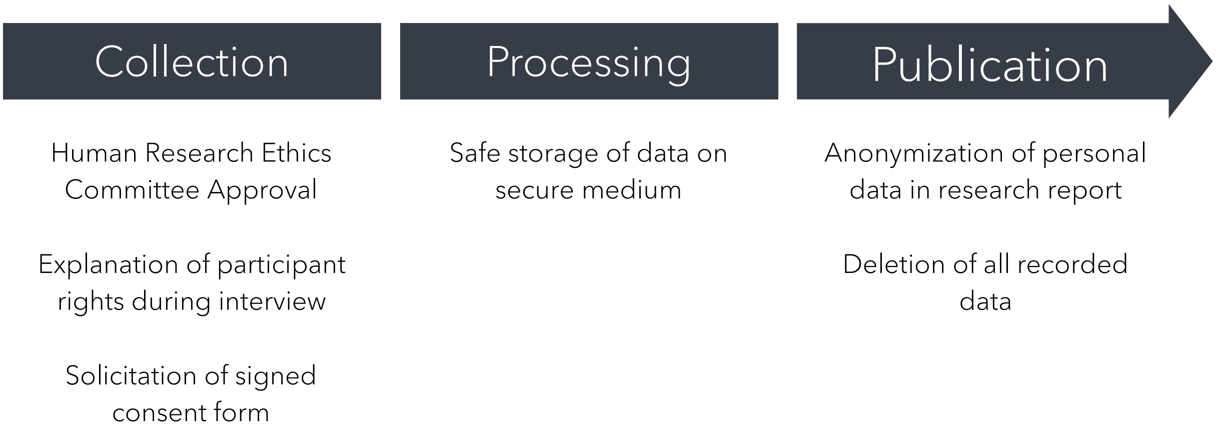

Figure 2.2 | Data management process overview

This thesis research project safely stores all recorded versions of the interviews on a secured medium (e.g., a secure cloud database) during the processing of the data. Any notes, transcripts or summaries of interviews are also stored on this medium while processing the data. Only the researcher (R.H.A. Lassooij) and the graduation committee supervising this thesis research project are granted access to this medium. Once the data has been processed and the thesis research project and its assessment by the graduation committee have been finalized, the data is discarded from the medium.

The insights retrieved from the interviews are reported in this thesis without sharing any specific data that can identify the individual or company from where the insights originated. This procedure allows this thesis research project to make use of the insights gained during the interviews without needing to share personal data.

2.3 Systems Modelling

While a data gathering phase can create summaries of data on the external developments (X), internal measures (L), and objectives (M), explaining the relations between these elements to stakeholders requires modelling.

To help stakeholders of a complex system, policy analysts have developed analytical tools to help deliberate on the effects of different measures under uncertain long-term conditions and communicate these to stakeholders (*Walker, 2000*). Systems modelling or diagramming are methods that can analyse and communicate the interactive relations in a complex system effectively by graphically representing these relations (*Sage, 1992*; *Walker, 2000*). This can allow for new insights to be inferred about the system that were not initially apparent and information to be more concretely communicated between stakeholders (*van der Lei et al., 2011*).

A crucial aspect to keep in mind when building a systems diagram is that systems diagram is only effective if it can convey the thinking of the builder of the model to the observer (*Haraldsson & Sverdrup, 2013*). Choosing the modelling technique should therefore be based on the target observer. As stakeholders in the Dutch IWT sector are generally not familiar with conceptual modelling practices in the academic world, this thesis research project opts for the use of a simple influence diagram modelling. Influence diagrams ultimately portray probabilistic and functional dependencies between factors by using basic shapes and arrows (see *Figure 2.3*) (*Sage, 1992*). It therefore offers expert stakeholders a practical means of characterizing the qualitative (and quantitative) relationships in a system of interest (*Schachter & Heckerman, 1987*). Its focus on the depiction of dependencies between factors could allow stakeholders to quickly understand the (uncertain) relations in the systems diagram instead of being distracted by advanced technical modelling practices. For this reason, influence diagrams have been used as graphical communicative devices in the past (*Howard & Matheson, 2005*; *Thissen, 2004*).

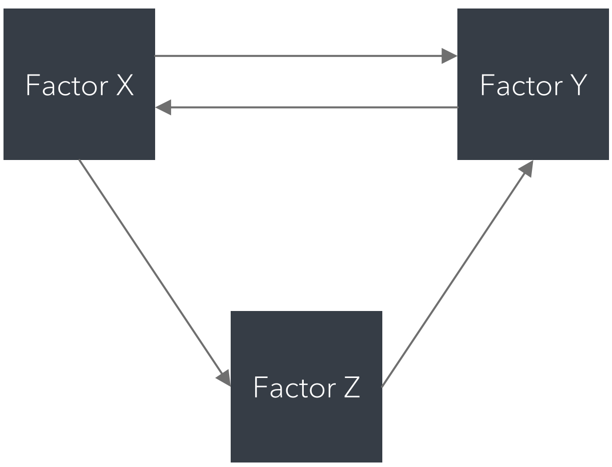

Figure 2.3 | Generic influence diagram

Naturally, other modelling techniques can conceivably be used to model the relations in the Dutch IWT sector, however, not all modelling techniques meet the criterion of being simple enough for stakeholders to understand. For instance, an issue with comprehensive causal loop diagrams (a specific type of influence diagram focused on system feedback) or a stock-flow diagrams is that such diagrams can become too elaborate, which can come at the cost of providing a clear overview to the observer (*Lane, 2000*; *Morecroft, 1982*). This thesis research project, therefore, seeks to use simplified influence diagrams.

2.4 Evaluation & Validation

The final step in the answering the main research question is the validation of the produced robust decision analysis. The objective of this validation step is to evaluate whether the produced robust decision analysis has potential in supporting IWT businesses in their long-term decision-making. By doing so, this thesis research project aims to establish the potential of robust decision analyses to the long-term decision-making in the Dutch IWT sector, thereby providing an answer to the main research question.

This thesis research project uses a framework of validation criteria developed by (*Thissen & Twaalfhoven, 2001*) that focusses on evaluation of research activities relating to policy analysis. These criteria are evaluated by conducting interviews with problem owners. Ultimately, by having problem owners examine the produced robust decision analysis based on the validation criteria with problem owners, this thesis research project aims to provide an answer to the main research question. Additionally, an evaluation of the robust decision analysis also offers the ability to iteratively improve the robust decision analysis with the feedback from stakeholders and gives stakeholders an opportunity to weigh in on the discussion of this thesis research project.

In the following sections, the framework that *Thissen and Twaalfhoven (2001)* use is explained and its implementation in this thesis research project is described. The results of the validation can be found in *Chapter 7* on *page 72*.

2.4.1 Theory of Validation of Policy Analytical Activities

In their research paper, *Thissen and Twaalfhoven (2001)* collect the findings from a wide group of authors in the policy analysis field and establish a framework for evaluating policy analytic activities. *Thissen and Twaalfhoven (2001)* elaborate that policy analysis should fulfill three purposes: provide information, constitute a participative policy-oriented process and function as a method. By validating whether the produced robust decision analysis fulfills these three purposes, it becomes possible to evaluate whether a robust decision analysis indeed offers any potential to stakeholders in the Dutch IWT sector.

Provision of Information

The traditional purpose behind policy analytical activities is to independently provide a group of decision-makers with unbiased scientific information to support in their decision-making (*Miser & Quade, 1985*). *Thissen and Twaalfhoven (2001)* propose three methods to measure the degree to which these objectives have been attained: analytical success, utilization success and outcome success. Since this thesis research project does not intend to implement the tool in a real-life situation, the tool cannot be used and therefore no outcome can be produced. The only method to measure the degree to which the tool provides unbiased scientific information that is useful to decision-makers is to measure its analytical success. *Thissen and Twaalfhoven (2001)* define analytical success to be based on how the activity was performed and how it was presented. Validation therefore includes a formal quality control on the technical validity, persuasive validity, timeliness, pertinence, and usefulness and the approval of selected parties (*Thissen & Twaalfhoven, 2001*). The description of each criterion is listed the table *below*.

Table 2.8 | Validation Criteria for Information Provision

VALIDATION CRITERIA	DESCRIPTION
Technical Validity and Verifiability	Precision of formulation, differentiation in aspects taken into account, internal coherence/consistency, empirical quality (*Hoogerwerf, 1984*)
Informative Usefulness	Ability to inform stakeholders with new insights
Pertinence & Timeliness	Relevance to the policy problem at hand with regards to subject matter and time

Facilitation of Participative Policy-Making Process

In addition to providing decision-makers with information, policy analysis is also intended catalyze debate and facilitate the participatory process of policy-making (*Thissen & Twaalfhoven, 2001*). Due to the fact that multiple stakeholders are involved in making decisions that affect the long-term viability of the IWT sector, it becomes beneficial if policy analysis is able to stimulate and facilitate debate between multiple stakeholders that enrich the decision-making process. *Geurts and Kasperkovitz (1994)*; *Geurts and Vennix (1989)* consider that policy analysis should be explored from as many different stakeholders as possible and that it should stimulate communication between a diverse range of stakeholders with different perspectives. A robust decision analysis should therefore be inclusive in the perspectives it represents and be able to communicate the findings between a diverse set of stakeholders (see table *below*). This would fulfill policy analysis' objective of facilitating the decision-making process.

Table 2.9 | Validation Criteria for Facilitation of Perceptive Process

VALIDATION CRITERIA	DESCRIPTION
Inclusiveness	Incorporation of diverse range of stakeholders with different perspectives
Communicative Usefulness	Ability to facilitate communication between diverse stakeholders

2.4.2 Process of Validation

As this thesis research aims to validate the produced robust decision analysis, it follows a process in which the results are verified to fulfill the objectives providing information and facilitating a participative policy-making process. This process is conducted by relaying the produced robust decision analysis back to the original participants of earlier interviews. These participants are questioned on whether, according to their expert judgement and their experience in participative decision-making, the results meet a set of validation criteria to the extent of fulfilling the objectives of providing information and facilitating the policymaking process.

3 Viability of the Dutch IWT Sector

SQ 1

What does the long-term viability of the Dutch IWT sector entail? (M)

In the proceeding chapters, this thesis research project has introduced the concept of long-term viability as the objective of the Dutch IWT sector. Generally, viability in the context of a business or industrial sector refers to the ability to continue operations successfully over time *(D'Souza, Wortmann, Huitema, & Velthuijsen, 2015*). The long-term survival of any industry or business is dependent on having a viable business model (*Magretta, 2002*). Businesses operating in a dynamic industry can therefore not afford to be too heavily invested in the short term without having a viable business model before sacrificing short-term success once the industry has moved on (D'Souza et al., 2015).

Although viability can be linked to long-term successful business models, this general definition does not yet necessarily explain what makes the business model of an IWT business successful in the long term. Questions remain as to what long-term objectives (M) should be maintained by IWT businesses in the Dutch IWT sector. To apply this general definition of viability onto the Dutch IWT sector and understand what objectives should be maintained, this chapter delves into the various objectives that IWT businesses pursue to lead to their long-term viability.

3.1 Profits in the IWT Sector

As is the case with any business, turning a profit is considered the main objective in leading a successful business. Profits are what is left over when subtracting the costs an IWT business has for providing a service (e.g., fuel costs, crew costs, etc.) from the revenue it makes on a given service (*LSP.1*). Profits can therefore either be increased through raising revenues or lowering costs (see *Figure 3.1*). Revenues can in turn be increased as result of more demand for IWT which increases the amount transported by IWT businesses as well as the IWT price overall (*Wiesenthal, Condeço-Melhorado, & Leduc, 2015*). A decrease in the available IWT capacity on the market will also increase the IWT price and revenues for IWT businesses (*Wiesenthal et al., 2015*).

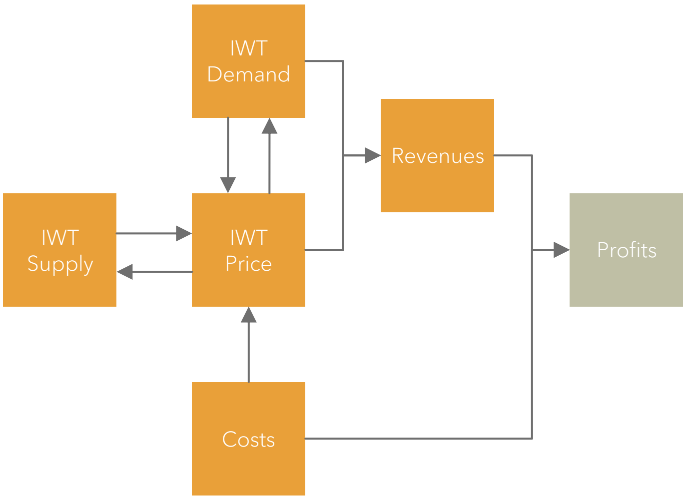

Figure 3.1 | Profits as a result of revenue and costs

Balancing the revenues and costs is what all IWT businesses do when deciding to take on an assignment from a *shipper* (*ISA.1; LSP.1; LSP.2; TAB.1*). This results in a market price for IWT services that is relatively equal for all IWT business (*Stopford, 2008*).

3.2 Long-Term Viability at Stake

Taking a long-term perspective on the IWT sector, it is in the interest of IWT businesses to find a way to retain IWT demand over, at the minimum, the lifespan of their assets (e.g., barge hull, motor, terminal upgrades, etc.). Only this way can IWT businesses safely and viably invest into their businesses with the hope getting a return on their investment (*de Lima et al., 2015*). While maximizing profits is a short-term objective of any IWT business (see '*Profits in the IWT Sector*' on *page 32*), the long-term collective ambition of the Dutch IWT sector is to ensure that transport demand remains viable so that IWT businesses can remain profitable in the future, thereby justifying the asset investments made in the present (see *Figure 3.2*).

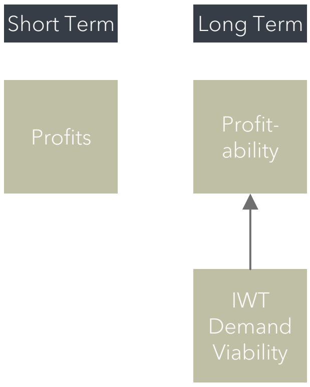

Figure 3.2 | Short term versus long term objectives

3.3 Objectives for Viable Transport Demand

In addition to understanding how short-term profits are induced by LRD periods, IWT businesses need to understand what pull factors of their business models drive the viability of the demand for IWT services to safeguard their future profitability. These pull factors function as objectives for IWT business within a viable business model.

Through interviews with problem owners in the Dutch IWT sector and shippers, a consensus over two main objectives was found. On the one hand, to attract demand for IWT services, the services needed to be able to compete with to other modes of transport in terms of price per tonne-kilometre (*SK.1; SK.2; SHTA.1; ISA.1*). On the other hand, the transport service needed to be reliable (*SK.1; SK.2; SHTA.1; ISA.1*). Demand for IWT services is created in the case when a shipper decides to offload the task of shipping their goods and resources to a chartered IWT business in the assumption that an independent specialist in IWT can offer a more affordable and reliable service than the shipper could provide itself with (*Stopford, 2008*). As a representative from a shippers' trade association mentions, a balance price competitiveness and reliability lays at the basis of the decision for a shipper to choose IWT over another mode of transport (*SHTA.1*). Every shipper chooses a transport service that can provide their desired balance of reliability and affordability that matches their needs. Optimizing for both is necessary in the sector and makes it competitive to other modes of transport. In the following sections, these objectives are elaborated on in further detail.

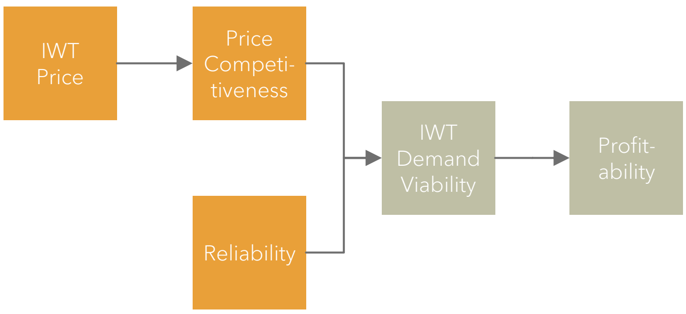

Figure 3.3 | Long-term objectives for viable transport demand

3.3.1 Price Competitiveness

As is supported by scientific research, the cost of transport services is generally considered one of the most important criteria for shippers in their choice for a mode of transport (*Bergantino, Bierlaire, Catalano, Migliore, & Amoroso, 2013*; *Danielis & Marcucci, 2007*). The economies of scale that IWT offers often makes it more price competitive compared to road or rail transport (*Wiegmans & Konings, 2015*). This is widely considered the major pull factor for shippers that choose IWT over other modes of transport as IWT often underperforms with regards to other criteria such as flexibility and time-efficiency (*Konings & Ludema, 2000*) (*LSP.1*).

While LRD periods only temporarily increase the IWT price and do not stimulate most shippers to offload shipments to other modes of transport (*Jonkeren et al., 2011*; *Wiegmans & Konings, 2015*), the occurrence of more frequent and lengthy LRD periods can cause the IWT price aggregated over time to increase as well. Over time, goods that are most price sensitive can be offloaded to other modes of transport. These include goods with higher price densities such as containers (*Kotowska, Mańkowska, & Pluciński, 2018*; *Meijeren et al., 2011*).

3.3.2 Reliability

While IWT's price competitiveness is considered the main pull factor for shippers' modal choice for IWT, reliability of transport delivery is a criterion that can be a dealbreaker for many shippers. Although most shippers can fall back on a certain amount inventory capacity, all shippers rely on transport services to eventually refill drained inventory or empty piled up raw material stock. Due to the cost of holding inventory, shippers generally prefer to rely on transport services as much as they can (*Blumenfeld, Burns, Diltz, & Daganzo, 1985*; *Nozick & Turnquist, 2001*). This practice, however, is dependent on a certain degree of *schedule reliability* of IWT services.

Depending on the goods that are transported, schedule reliability can be a matter of delivering goods on a specific day or within a certain week. Requirements with regards to schedule reliability stricter when it comes to container shipping when compared to other transport goods such as bulk goods (*SK.2*). As container shipping lines are part of an efficient global supply chain that often relies on just-in-time practices, their shipment becomes highly time-sensitive and the schedule reliability becomes a major factor when considering to transport via IWT (*Chung & Chiang, 2011*). According to *Chung and Chiang (2011)*, when selecting a logistical service provider to transport containers, shippers' main concern is the schedule reliability. Shippers are more willing to pay higher sums for shipment that can be guaranteed a certain schedule reliability (*Chung & Chiang, 2011*). Low schedule reliability of transport services would require shippers to spend more on inventories to compensate for late deliveries and could lead to increased production costs attributed to possible interruptions in production due to lack of materials (*Notteboom, 2006*).

Key Findings of Chapter 3

1. The success of an IWT business is measured in terms of profits in the short-term
2. The long-term viability of the IWT sector relies on long-term profitability, which depends on the viability of IWT demand in the long term
3. The short-term objectives of IWT businesses are counterproductive to achieving long-term viability, as exploitation of current IWT demand during LRD periods does not lead to viable long-term demand
4. Long-term viability of the IWT sector implies maintenance of a balance of price competitiveness and reliability

4 External Developments

SQ 2

What are the external developments affecting the long-term viability of the Dutch IWT sector? (X)

In this fourth chapter, an analysis is presented on the external developments (X) that affect the Dutch IWT sector in the context of the future navigation of the Rhine. A broad scouting through various issue papers and consultations with various stakeholders of the Dutch IWT sector show that the sector is challenged by a number of uncertain developments external to (i.e., outside the control of) the decision-making of IWT businesses. This chapter provides a summary of these external developments and analyzes the effect of these developments on the objectives of the IWT sector.

The strict demarcation of the Dutch IWT sector (see *'IWT Businesses as a Problem Owner'* on *page 7*) enables the drawing of a clear distinction between external developments and internal developments (i.e., internal measures). While decisions on the business operations and strategic planning may be considered uncertain developments as they can change with time, these are endogenous to the decision-making of IWT businesses, meaning they are within the control of individual entities within the sector. Within the XLRM framework, internal measures are considered policy levers (L) and encompass all actions that IWT sector can take in response to or in anticipation of external developments.

Within this chapter, this thesis research project presents two categories of external developments that influence the Dutch IWT sector in the context of the future navigability of the Rhine. These categories can be split along the line of developments that influence the manifestation of LRD periods and economic external developments that impact the service demands of the IWT sector during LRD periods.

Table 4.1 | Summary of Areas of External Uncertainty

LRD DEVELOPMENT	Climate Change
	River Morphology
	Government Action
ECONOMIC DEVELOPMENTS	Development of Transport Service Demand

4.1 Development of the Manifestation of LRD Periods

Developments related to the environment that affect the IWT mostly covered by changes to *river hydrology*. Navigation on the Rhine is influenced by the hydrological conditions of the Rhine such as river depth and flow velocity (see '*Problem*' on *page* 1). Developments in river hydrology can therefore enable or hinder navigation.

River hydrology (i.e., river discharge) naturally adjusts over time[5] with changes to the amount of run-off that is fed into a river (partly induced by climate) and the geophysical properties of the river (*Shiklomanov & Lammers, 2013*). In the future, there are two identifiable, interacting, uncertain developments that can alter river hydrological patterns. This includes factors relating to changes in climate (i.e., long-term patterns of weather) and *river morphology*. The following subsections explain how these factors have a plausible, yet uncertain, effect on river hydrology.

4.1.1 Climate Change

In the summer of 2018, northwestern Europe experienced a prolonged heatwave *(Kornhuber et al., 2019*; *World Weather Attribution, 2018*). The combined effect of high temperatures and low precipitation led to a *precipitation shortfall* in 2018 (*see Figure 4.1*) (*Sluijter, Plieger, van Oldenborgh, Beersma, & De Vries, 2018*). Although the summer of 2018 was a statistical anomaly within the last three decades (*Kramer, 2018*; *Philip, Kew, van der Wiel, Wanders, & van Oldenborgh, 2020*), long-lasting droughts have become more common in northwestern Europe than they were three decades ago (*Bakke, Ionita, & Tallaksen, 2020*; *Spinoni et al., 2019*).

[5] *To clarify, changes to hydrology on a seasonal basis are related to meteorology and constitute what is called a river's hydrological regime* (Zeiringer, Seliger, Greimel, & Schmutz, 2018*). In this thesis research project, the focus is put on long-term developments to hydrological regime*

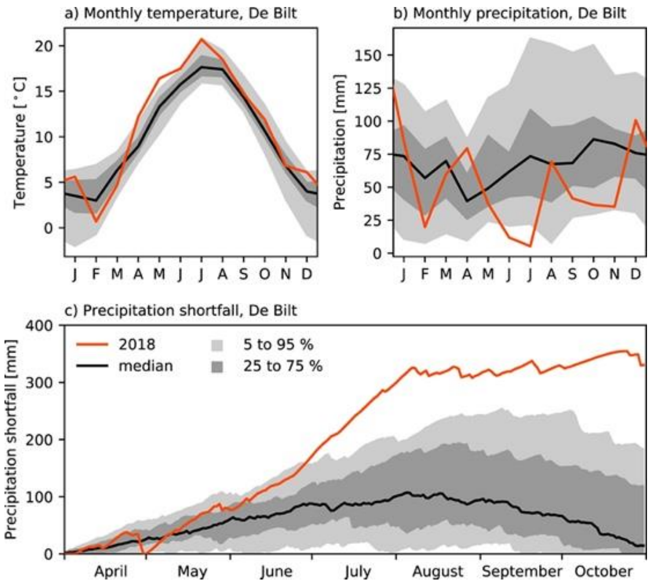

*Figure 4.1 | Time series of Rhine temperature and precipitation (a) monthly temperature [°C], (b) monthly precipitation [mm] and (c) daily precipitation shortfall (cumulative potential evapotranspiration minus precipitation, set to zero if smaller than zero) [mm] for station De Bilt, the Netherlands (*Philip et al., 2020*).*

Moreover, studies have indicated that a direct link can be made between general precipitation shortfall occurrences in summer months in northwestern Europe and global climate change (*Naveau et al., 2018*; *Yiou et al., 2020*). Heatwaves, like the one experienced in 2018, may become more common in northwestern Europe (*Stott, Stone, & Allen, 2004*). Based on the latest *IPCC Assessment Report 5*, the Royal Dutch Institute of Meteorology (KNMI) projects that, in a worst-case climate change scenario, the Netherlands will be subject to a 2.3 degree Celsius rise in temperature and a halving of precipitation levels during the summer months by 2050 (*Klein Tank, Beersma, Bessembinder, van den Hurk, & Lenderink, 2015*). Studies on summer precipitation, however, are less conclusive (*van Haren, van Oldenborgh, Lenderink, Collins, & Hazeleger, 2012*), thereby increasing the necessity to give precedence to worst-case projections, which are characterized by sporadic heavy showers and long periods of drought (*Klein Tank et al., 2015*).

Due to the reduced Alpine meltwater discharge during the summer months, the Rhine has turned into a predominantly *rainfall driven system* (*Junghans, Cullmann, & Huss, 2011*; *Middelkoop et al., 2001*; *Middelkoop & Kwadijk, 2001*). This becomes problematic as more frequently occurring droughts in the main *Rhine-catchment area*, due to climate change, can now lead to low discharge levels (*International Commission for the Protection of the Rhine, 2015*; *Mens et al., 2018*; *Rozemeijer et al., 2021*). From 1950 to 2019, precipitation during the summer period (June-November) thus far decreased by 14% over the Rhine-catchment area, bringing about a 9% reduction in Rhine discharge in the summer period (*Philip et al., 2020*). This general decrease in river discharge rendered the Rhine susceptible to extremely low discharge levels[6] as witnessed in the summer of 2018 (*Directorate-General for Public Works and Water Management, 2018*; *Philip et al., 2020*; *Schuetze, 2018*).

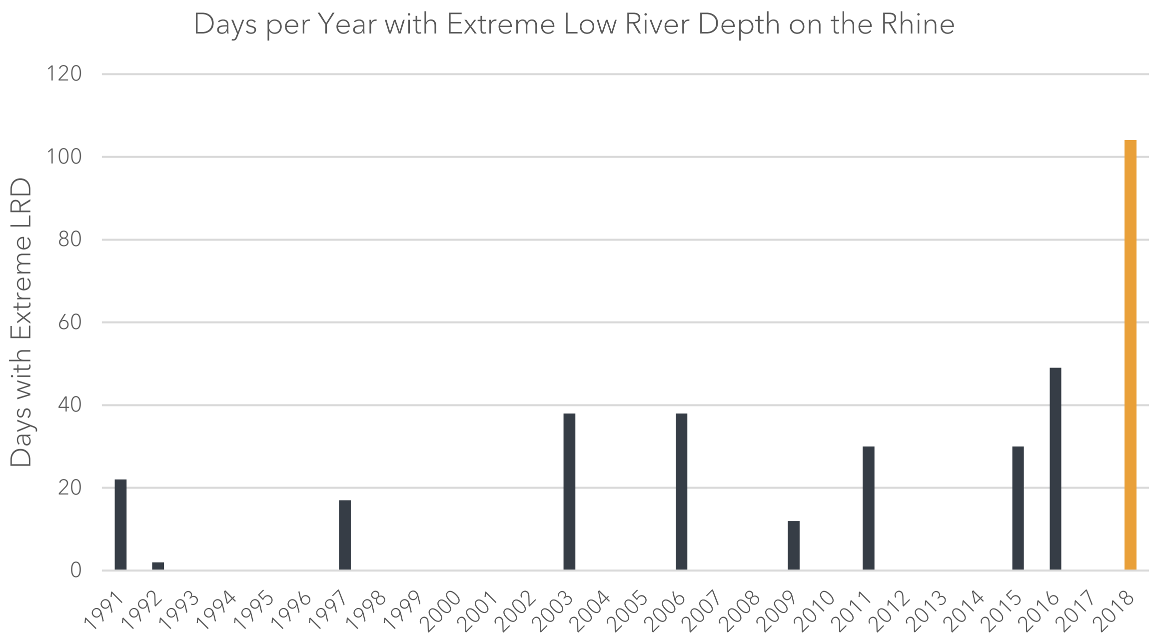

Figure 4.2 | Number of days with extremely low river depth per year (water level at Kaub <78cm ≈ 800 m3/s at Lobith) (Ademmer et al., 2019)

Over the last two decades, the decreased Alpine meltwater and precipitation has led to an increased frequency of months with extremely low discharge and increased duration of periods of extremely low discharge (*Ademmer et al., 2019*; *Flörke et al., 2011*) (see *Figure 4.2*). Taking the climate change scenarios from the KNMI at face value, discharge levels in the Rhine will on average possibly decrease by a further 27% during summer months, which would structurally expose the Rhine to extremely low discharges during drought periods (*Sperna-Weiland et al., 2015*) (see *Figure 4.3*).

[6] Low discharge for the Rhine can be defined to lie between 1300 m^3/s and 800 m^3/s. Discharges lower than 800 m^3/s are extremely low. All discharge levels are presented concern the discharge levels at Lobith, unless specified otherwise

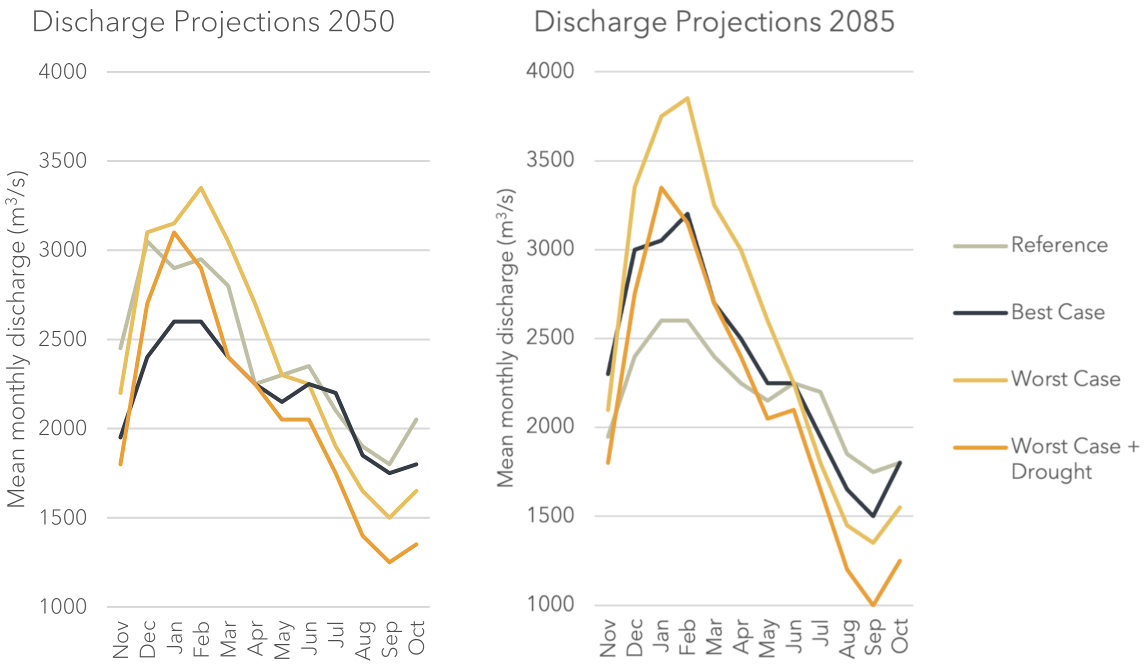

Figure 4.3 | KNMI's average monthly discharge projections at Lobith in comparison to the current (reference) situation (Sperna-Weiland et al., 2015)

Due to the remaining channel being relatively narrow during LRD periods, any further decreases in discharge reduces the river depth significantly (*Bilgili, 2018*) and renders transporting freight on the Rhine less economical as *load factor* need to be reduced, increasing costs per ton shipped and reducing the *competitiveness* of IWT against other modes of container transport (*Flörke et al., 2011*; *Jonkeren et al., 2007*; *Rothstein & Scholten, 2014*). Fleets without shallow draught barges are immobilized by extremely low river depths, which jeopardizes their reliability to ship freight on time (*van Dorsser, 2015*). The rise in transport costs and the decline in reliability may lead shippers to shift to other modes of transport (e.g., rail or road transport) (*Arnold, 2009*; *Jonkeren et al., 2011*; *Klein Tank et al., 2015*). Knowing of the uncertainty surrounding developments outside of their control, mainly with regards to the Rhine's navigability, IWT businesses are left with the question on how they should secure their competitiveness against other modes of container transport.

4.1.2 River Morphology

The development of river flow and the impact of LRD periods on IWT businesses over time is not solely determined by climate factors, but also is dependent on river morphological development. Erosion of the riverbed or accumulation of sediment at certain segments of the river (see *Figure 4.4*) can affect the localized river depth and thus affect navigability of the river. The uneven erosion of the riverbed and accumulation of sandbanks has resulted in the formation of shallows at certain segments of the river (*Spreafico & Lehmann, 2009*). Simultaneously, erosion of the natural riverbed segments shortly upstream from previously instated non-erodible (man-made) riverbeds has also created shallows (*Blom, 2016*; *Hakstege, 2013*; *van Reen, 2002*). The projections for overall *bed degradation* warn that a 0.2 meter to 1 meter decrease in some areas of the Rhine will be likely until 2100 (*Termes &*

Huthoff, 2006), which (ceteris paribus) will cause overall *water levels* in the river to fall, thereby creating shallower river segments at non-erodible segments of the Rhine during periods of low river discharge (*Krekt et al., 2011*). Even if the Rhine riverbed would degrade evenly over the entire profile, these non-erodible riverbeds would continue to form shallow segments in the river.

Figure 4.4 | Mean annual change of riverbed between 1981 and 1990 (Spreafico & Lehmann, 2009)

4.1.3 Government Action

Ultimately, the changes in river morphology have made dredging and suppletion of certain segments a necessary and permanently recurrent maintenance measure to keep the riverbed even and the navigability of the Rhine up to standard (*Bardoel, 2010*; *Havinga et al., 2006*). To ensure navigability of the Rhine, the Ministry of I&W of the Netherlands currently employs recurrent dredging and suppletion practices (*Directorate-General for Public Works and Water Management, 2015*), however, these measures, besides being financially unsustainable, are not an inexhaustible solution, as river depth cannot be maintained by dredging and suppletion indefinitely in future scenarios in which there is less river discharge (*Havinga, 2020*; *van Vuren, Paarlberg, & Havinga, 2015*).

Other more drastic measures include the building of longitudinal dams and weirs (*Taekema, 2017*), which have the negative consequence of impairing the thus far unrestricted passage on the Rhine[7] and being very costly to build (*Krekt et al., 2011*). Further modification to the river (e.g., *groynes* and *longitudinal dams*) can possibly counteract the necessity of dredging and suppletion and make maintenance more sustainable (*Akkerman, van Heereveld, Barneveld, & Smedes, 2006*). Groynes, for instance, aim to slow the flow rate of the river and thereby increase river depth, while longitudinal dams target a narrowing of the river, which would increase river depth at a given river discharge. While infrastructural measures can theoretically counteract the possible decrease in river discharge because of climate change and the loss of river depth as a result of conceivable further progression of riverbed degradation, it is uncertain if governments of the Rhine riparian states will implement these measures. The following three subsections explain why government action on infrastructural measures is uncertain.

Government's Legal Responsibility

In the 19th century, the Rhine's socio-political and economic importance grew as it started be used an to connect more mines, farms, factories and cities (*Wilken, 2006*). This led to an increased interest in its political regulation and investment into its canalization (*Wilken, 2006*). As a result, Article 28 of the Treaty of Mannheim (*1868*) was signed by all *Rhine riparian states* and imposed the responsibility on their governments to maintain the Rhine in such a way that upholds navigational conditions to a degree that is suitable for navigation[8]. Government agencies of the various Rhine riparian states have since undertaken periodic maintenance work to sustain river flow at levels that can facilitate navigation by executing various river training projects and conducting routine dredging and suppletion.

Since the Treaty of Mannheim was signed in 1868, governments have signed further international agreements that prescribe specific target river depths and widths (see *Figure 4.5*). For every segment of the Rhine, a target depth and flow, designated as the *Equivalent Water Level (GlW[9])* and the *equivalent flow rate (GlQ*[10]) respectively, were agreed upon. International agreements following the Treaty of Mannheim stipulate that the Rhine's discharge should only, during 5% of the year, fall below the discharge level historically exceeded on average 345 days (~95%) per year (*Commission of Engineers, 1932*). The GlQ, and by extension the GlW, can thus vary depending on the chosen period of examination. For the Rhine's entry point into the Netherlands at Lobith, the currently agreed upon GlQ was based on the average river discharge rate between 1901-2000 and is set at 1020 m^3/s (*Koolwijk, 1992*; *Stuurman & Koolwijk, 2003*). The corresponding GlW was set at 2.8 meters, while the width of the Rhine at equivalent water level was established to be 150 meters (see *Figure 4.5*).

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[7] *Unrestricted from Rotterdam, the Netherlands to Iffezheim, Germany*

[8] *This is an interpretation of the law* (Centraal Overleg Vaarwegen, 2018*). The literal citation in the treaty states that waterways should be maintained in "good condition" (from original French: bon état)*

[9] *From German; Gleichwertiger Wasserstand (GlW)*

[10] *From German; Gleichwertiger Quelle[Abfluss] (GlQ) – discharge rate*

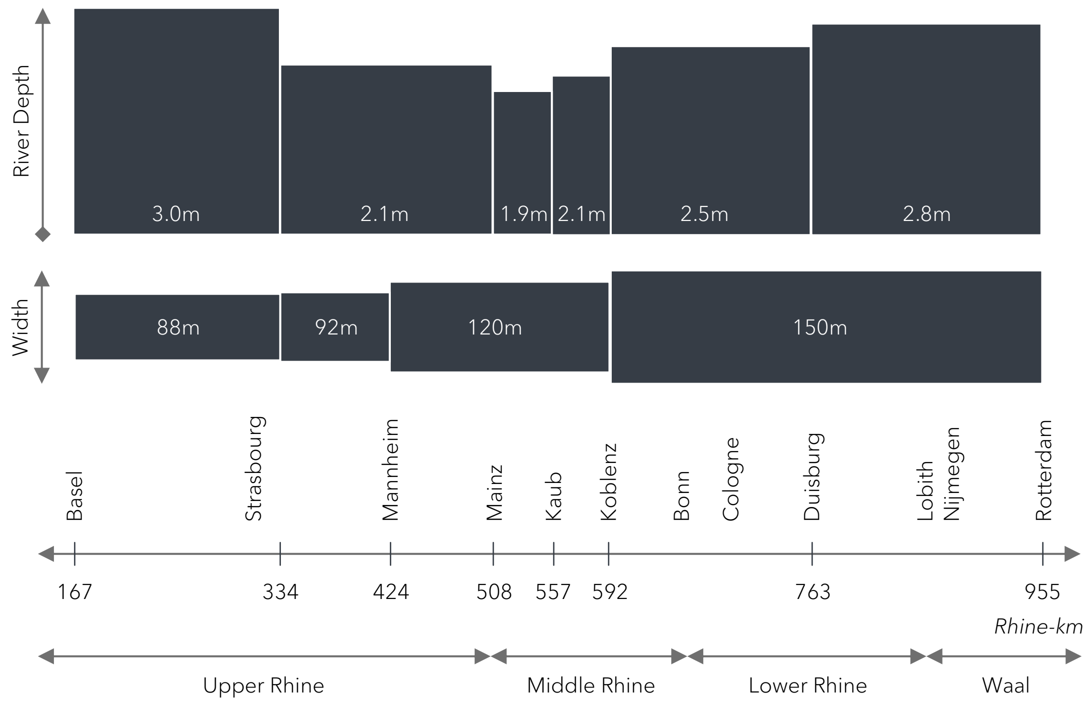

Figure 4.5 | Waterway profile of the Rhine as specified by CCNR
(Central Commission for the Navigation of the Rhine, 2012)

The problem with portraying the ratio between the GlQ and GlW as a legal limit is that the objective of the ratio is to function as a reference to measure whether dredging projects have been sufficient at keeping the river depth stable over a ten year period (*Douben & van der Veen, 2001*). Although the ratio encompasses a hydrological target value, this target is only temporary as it is re-evaluated and negotiated every ten years (*Koolwijk, 1992*). In 2002, the current ratio between the GlQ and GlW at Lobith was negotiated between the Netherlands and Germany (*Stuurman & Koolwijk, 2003*). However, there is no legal guarantee that the ratio will not be renegotiated. As historical precedence can demonstrate, the GlW, as a function of the GlQ, was also renegotiated in 1996 to increase 2.5m to 2.8m in an effort to accommodate vessels with larger *draughts* (*Douben & van der Veen, 2001*). Regardless of previous negotiations, the required dredging to sustain the GlW of 2.8m may become socio-economically unsustainable and ultimately lead to a renegotiation of the GlW between the Rhine riparian states.

While the Treaty of Mannheim (*1868*) and consequent agreements provide IWT businesses with sufficient legal grounds to hold governments accountable for not maintaining the Rhine's navigability, it is uncertain whether they specifically mandate that river depths need to be maintained at the agreed upon target river depth. This would in some cases necessitate governments to invest in expensive infrastructure projects.

The uncertainty of climate change and its effect on river hydrology places the previous discussion over legal responsibility into further perspective. The discussion over the legal responsibility and technical ability to sufficiently maintain the Rhine to sustain the ratio between GlQ and GlW becomes irrelevant when considering that the GlQ is projected to possibly dissipate.

Since the measure of the GlQ varies according to the conditions of the Rhine, it should not be expected to stay at 1020 m^3/s. Over the last century, historical precedent has shown that the GlQ has often been lower than 1020 m^3/s (see *Figure 4.6*). Only by taking the average of the last century can a GlQ of 1020 m^3/s be justified (*Stuurman & Koolwijk, 2003*). It is therefore conceivable that, regardless of current negotiations, GlQ levels can be renegotiated to fit the future discharge of the Rhine. In a best-case scenario, the GlQ is projected to be maintained at around 1020 m^3/s (*Yossef & Sloff, 2012*). However, in the worst case, the GlQ may drop to 634 m^3/s (*Yossef & Sloff, 2012*), which would give governments a firm legal and technical reason to lower the GlW in future negotiations.

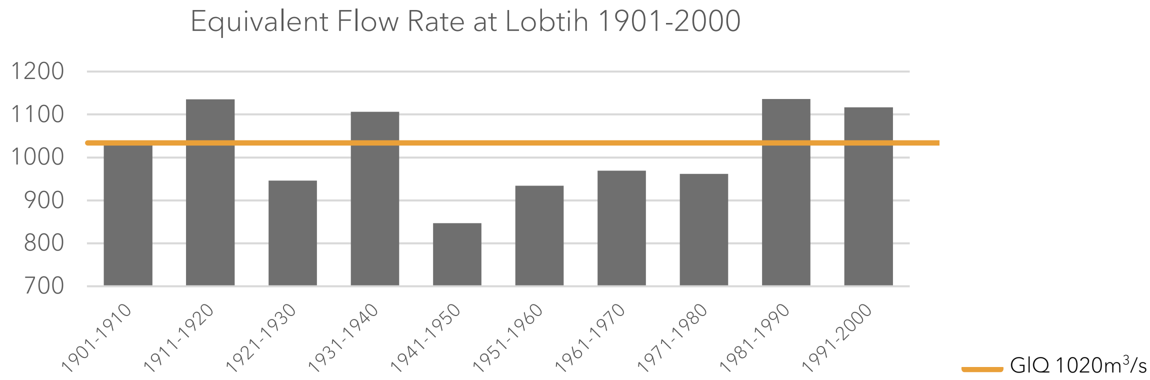

Figure 4.6 | Equivalent flow rate 1901-2000
*(*Stuurman & Koolwijk, 2003)

Once one has acknowledged that climate change may decrease river discharge and thereby complicate the government's efforts of maintaining the GlW of 2.8 meters, it becomes a significant risk to solely rely on governments to increase sediment management efforts to a sufficient extent. If dredging and suppletion practices cannot match the pace of erosion, other measures would have to be deployed (*Akkerman et al., 2006*). Governmental institutions on Rhine navigation are already sending out a warning to IWT businesses that government measures on river infrastructure are possibly insufficient to maintain the GlQ of 1020 m^3/s and that action from IWT businesses will be required to ensure the long-term viability of the IWT sector (*International Commission for the Protection of the Rhine, 2013*; *Kempmann & Roux, 2020*).

<u>Government Interests in the Rhine</u>

Although a cost-benefit analysis can potentially give clarity which measures are worth investing from an economic perspective for the IWT sector, it cannot easily give answers to governments on how to balance other interests in the Rhine. Besides facilitating navigation, these measures could have effects on safety against flooding, freshwater supply, agriculture dependent on the Rhine and the ecology of the river (*Havinga, 2020*). Threatening these interests will induce more political discussion (*Willems, 2018*). Deliberating on which measures to implement becomes highly complex when considering, in addition to the interests of the IWT sector, other societal interests regarding the Rhine (*Havinga, 2020*). In response to measures solely focused on individual interests increasingly leading to conflicts with other interests, a so-called *Integrated River Management Approach* won favour with river managers (*Havinga, 2020*; *Mosselman, 2020*; *Smits, Havinga, Marteijn, & Nienhuis, 1998*; *Sustainable Development of Floodplains, 2008*). Within Integrated River Management, the costs and benefits to various interests such as flood risk management, drinking water supply, river ecology, industrial cooling, agricultural irrigation, and navigation are evaluated for infrastructural measures to the inland waterway. This means that navigation cannot be implemented without considering the costs to other interests. While measures that could potentially benefit the navigability of the Rhine during LRD periods, can have more impactful negative consequences on other societal interests. For example, measures such as longitudinal dams or weirs can be beneficial to navigation of the Rhine but have negative consequences on the ecology of the Rhine (*Zeiringer et al., 2018*). The consideration between various interest in the Rhine can lead to a narrowing of the solutions governments can implement to improve navigability.

Although the interests of the IWT sector are a key concern in the integrated approach to river management, the Ministry of I&W of the Netherlands has forsaken its internationally binding commitment of upholding a GIW in the Rhine of 2.8m (*Centraal Overleg Vaarwegen, 2018*). In the years 2016 to 2018, the GIQ on average dropped below 2.8m during 70 days per year (~20% of the time) (*Centraal Overleg Vaarwegen, 2018*). Despite acknowledging the issue and its failure to meet its international commitment to target river depths (*Government of the Netherlands, 2019*), the Directorate for Public Works and Water Management (Rijkswaterstaat) has established it cannot provide sufficient action (*van Heel, 2020*) (*GA.1; GA.2*).

In a 2019 policy roundtable on future droughts (Droogtetafel), between various governmental parties in the Netherlands, it was decided that Rijkswaterstaat will proceed in further studying what it can do to increase the climate resilience of the Rhine (*Ministry of Infrastructure and Water Management et al., 2019*. In the meantime, governmental parties agreed that the IWT sector needed to undertake its own action in becoming more climate resilient (*Ministry of Infrastructure and Water Management et al., 2019*). This same sentiment was echoed by German counterparts, as the Federal Ministry of Transport and Digital Infrastructure made it clear that the IWT sector was expected to come up with innovative solutions (Federal Ministry of Transport and Digital Infrastructure [BMVI], *2019b*).

Considering Rijkswaterstaat's hesitancy to bring forward a plan, its insistence on action from the private sector and the need to the costs of infrastructural measures to other interests within its integrated approach, it becomes sensible for IWT parties to account for scenarios in which government's action proves to be inadequate in guaranteeing a GIW of 2.8 meters.

International Cooperation

The Central Commission for Navigation of the Rhine (*CCNR*) is the first and, therefore, oldest international organization in modern history dating back to its creatin in 1815 (*Central Commission for the Navigation of the Rhine, 2016*). International cooperation on the Rhine has been prolonged due to the international shared mutual interests in the management of the Rhine (*Wilken, 2006*). As previously mentioned, river training projects at a specific location in the Rhine can have far reaching effects on river flow and river depth at other parts of the river (see '*River Morphology*' on *page 40*), which makes international cooperation necessary.

Although international cooperation on the management of the Rhine has endured for more than two centuries, there remain uncertainties in how international cooperation will develop in the future. Breaks in equal commitment to the Rhine's maintenance can result from differences in financial resources needed to maintain the Rhine's navigability. In the Netherlands, an abundance of water means that climate change will possibly put less stress on the Waal relative to the Upper Rhine and Middle Rhine. This results in German and French segments of the Rhine being impacted more heavily by LRD periods (*LSP.2*). Other governments may favour different solutions to the unnavigability of the Rhine if the costs of maintaining navigability of the Rhine do not weigh up to the national interests the Rhine can deliver.

Besides a difference in the financial resources necessary to maintain each nation's respective segments, a divergence of national interests in the Rhine may also jeopardize international cooperation. While the Dutch government prioritizes the Rhine's navigability for the sake of being able to service the European *hinterland*, the German government's interest in the Rhine's navigability lies in the access it provides for goods to be transported to seaports. Faced with tackling the issue of reduced river flow due to climate change, each nation can have different priorities with regards to their national interests. Germany's national response to an increasingly unnavigable Rhine may not be to invest more in the maintenance of the Rhine, but to invest in other transport infrastructure such as strengthen rail transport capacity to German ports in Hamburg and Bremen (*LSP.1; SH.1*). In some cases, the German government might abandon maintaining the Rhine River in favour of moving industries closer to German ports (*SH.1)*.

Due to the discrepancies in costs to and benefits of Rhine maintenance under climate change, an uncertainty arises on how governments of the Rhine riparian states will cooperate. This ultimately increases the uncertainty in the development of the river hydrology and can pose a risk to the long-term viability of the Dutch IWT sector.

4.2 Development of Transport Service Demand

As is common knowledge within the IWT sector, the market for goods transport in the long-term is more demand-led than supply-led (see '*Long-Term Viability at Stake*' on *page 32*) (*LSP.1; LSP.2*). The fact that ITW businesses mainly serve basic industries (i.e., container transport, bulk transport, etc.) makes the sector sensitive to fluctuations in the economic climate of the region (*Jonkeren et al., 2014*). This means that the IWT sector is dependent on the intensity of economic activity of industries along the Rhine.

The uncertainty surrounding the persistence of industries along the Rhine is significant. As a representative from a German steel producer warned, it is thinkable that their business and others can pack up and leave to other locations in response to changing conditions (*SH.1*). In the previous centuries, industrial businesses have located their operations near the Rhine for the access it provides to the *seaports* in the Netherlands and Belgium (*Grazhdankin, 2012*). The threat of environmental regulation and higher shipping costs can incentivize these businesses to relocate (*SH.1*), thus decreasing the demand for shipping along the Rhine.

While the possible relocation of certain industries brings uncertainty to the demand for shipping, a shift in the type of demand adds to this uncertainty. While the IWT on the Rhine is mostly composed of bulk transport, potential increases in containerization transport demand can bring changes to this proportion. While the demand for transportation of bulk goods is expected to decrease due to further stepping away from heavy industries, the demand for container transport is expected to fill its place (*LSP.1*). A logistics service provider specialized in both the transportation of bulk goods and containers, believes that his business and the rest of the sector will be able to adapt a potential shift (*LSP.1*). He explains that if demand for a certain type of goods transport changes, the price for shipping will respond and the IWT sector will adapt to fulfill the demand (*LSP.1*). A skipper provides details from his own experience that when demand shifts to a different type of goods transport, the sector can adapt quickly due to a vessel's versatile deployability (*SK.1*).

Although growth of demand for container transport can compensate losses in bulk transport demand, a shift from the transportation of bulk goods to containers will pose new challenges. Unlike bulk goods, container transport is highly time-sensitive and subject to stricter competition from other modes of transport. This will put the Dutch IWT sector under more pressure to maintain its reputation as a reliable mode of transport in scenarios where LRD periods are more intense, frequent, and time-extensive (see '*Reliability*' on *page 34*).

4.3 External Developments and the Dutch IWT Sector

In sum, this chapter has identified two major types of external developments that can affect the Dutch IWT sector in the context of the future navigability of the Rhine.

Firstly, external developments affecting the navigability of the Rhine include the uncertain development of climate change, the uncertain river morphological development and the uncertain implementation of government infrastructural measures that could improve navigability of the Rhine. The uncertainty in the progression of these three developments causes the development of future occurrences of LRD periods to be uncertain. While the development of climate change affects how intensely, frequently and time-extensively low river discharge periods can occur within a given summer-period, the development of riverbed erosion and government infrastructural measures on the Rhine can influence how these low discharge periods translate into the manifestation of LRD periods. While this chapter gives an elaborate explanation on the uncertain developments influencing the manifestation of LRD periods, the following chapter in this thesis research project simplify the external developments by implying that the development of the intensity, annual frequency and duration of LRD periods is uncertain due its causal relation to the uncertain external developments mentioned in this chapter.

Secondly, transport service demand development has been identified to be an uncertain development that can affect the Dutch IWT sector in scenarios in which the future navigability of the Rhine has deteriorated. An uncertain shift towards container transport service can increase the need to provide reliable and price competitive services.

4.3.1 The Influence of External Developments on Objectives

As was concluded in *Chapter 3*, IWT demand and IWT supply influence the profits of an IWT business (see *Figure 4.7*). This chapter has presented two types of external developments that influence the IWT demand and supply. Firstly, external developments in the manifestation of LRD periods influence the supply of IWT capacity. While the intensity of an LRD period has a direct relation to the supply of IWT, the annual frequency and duration of LRD periods have more complex relations to the supply of IWT. The more frequently LRD periods occur within a summer period, the more often supply of IWT capacity will be drained, however, depending on the duration of these LRD periods, IWT businesses can conceivably delay shipments until the LRD period has surpassed. Due to the inelasticity of IWT supply, IWT prices for shippers increase dramatically during LRD periods. In some cases, the physical barriers of LRD can disable navigation at any price (*LSP.1; SK.2*). Some shippers can temporarily shift transport to other modes of transport. However, some shippers are unable to shift to other modes of transport and must deal with delays and shortages in supply at production facilities or an overflow at raw material sites. Besides increasing the IWT price, the inelasticity of IWT supply and physical barriers of IWT also cause some shippers to be left without shipment during LRD periods.

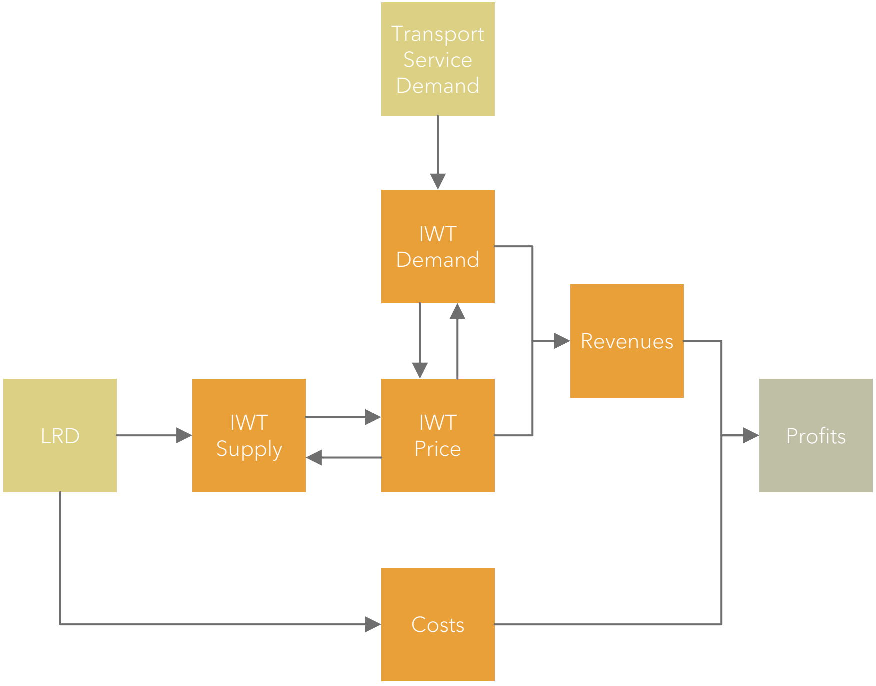

Figure 4.7 | Profits influenced by external developments in the short term

Secondly, external transport service demand development influences the requirements with regards to the reliability of IWT businesses during LRD periods. While not having a directly translatable effect on the IWT demand, a shift towards container transport will increase the need to offer reliable IWT services. In the short term, this additional requirement for reliable shipment will increase the demand during LRD periods.

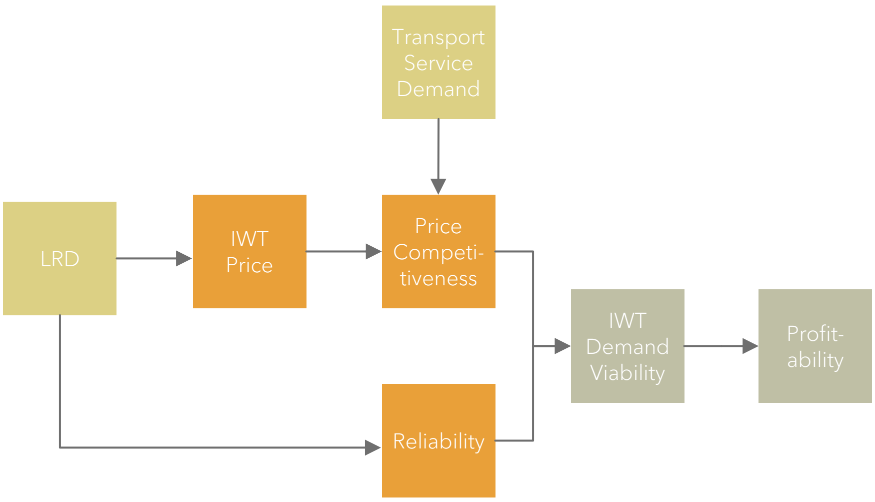

Figure 4.8 | Influence of external developments in the long term

While a single occurrence of an LRD period increases the IWT price temporarily due to capacity shortages thereby swelling short-term profits (see *Figure 4.7*), these increases in IWT price do long-term damage to the viability of the IWT sector. Focusing solely on the exploitation of increased IWT demand during LRD periods for short-term profits without regarding the original pull factors (price competitiveness and reliability) of IWT that created the demand for IWT services is an unviable business model. Likewise, if the transport service demand shifts towards container transport, IWT businesses will be put under more pressure to adhere to the providing a price competitive and reliable service.

Key Findings of *Chapter 4*

1. There are external developments that are uncertain and have an influence the Dutch IWT sector
2. These external developments can be summarized as developments that influence the long-term manifestation of LRD periods and the long-term goods transport service demand
3. External developments can have a threatening influence on the long-term IWT demand viability

5 Internal Measures

SQ 3

What internal climate change adaptation measures could safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (L)

Internal measures are near-term actions that IWT businesses can take to take in response to or in anticipation of external developments to the sector. In the context of the future navigability of the Rhine, internal measures that IWT businesses deliberate on are targeted towards the continual ability to provide price competitive and affordable transport services to shippers in scenarios in which LRD periods become more severe, frequent, and time extensive and the requirements for reliable shipment are heightened due to a shift towards container transport. Internal measures can be combined in various ways to ultimately compose comprehensive strategies to combat potential deterioration of the navigability of the Rhine and to provide reliable IWT services during LRD periods.

This chapter provides an inventory of different internal measures that IWT businesses can take to provide price competitive and reliable IWT services in future scenarios in which LRD periods are more severe, frequent and time extensive and container transport makes up a higher proportion of IWT demand. While the internal measures mentioned in the following subchapter intend to adapt the IWT sector to the various external developments, for simplicity's sake, this thesis research project uses a term that is commonly used to describe these measures and calls them climate change adaptation measures.

5.1 Internal Measures for Robustness

The list of potential internal climate change measures provided in this subchapter is the result from findings from the desk study and the processing of the suggestions made during interviews with a broad selection of stakeholders of the Dutch IWT sector on their perspective towards preparing the sector for the previously acknowledged external developments. The list contains measures that have either not been implemented yet or only been deployed sparingly until now. Measures involve making changes to the fleet management, logistic management, and information management of IWT carriers. This chapter attempts to provide an overview of the different measures by grouping them into three clusters.

Table 5.1 | Internal Measures Classification

TYPE OF MEASURE	DESCRIPTION
Fleet Management	Deploying barges whose load capacity is affected relatively less during LRD periods
Logistic Management	Improvement of the resilience and flexibility of supply chains
Data Management	Utilization of data and models to predict patterns of demand and navigability

5.1.1 Fleet Management

This category of internal measures involves the construction or adaptation of barge(s) that an IWT businesses deploys so that its *deadweight* is less affected during LRD periods. Changing the properties of the fleet can make IWT businesses more flexible in the way they deal with LRD periods. Enhancing the flexibility of how barges can be deployed allows IWT businesses to be more resilient during periods of LRD.

<u>Low Draught Barges</u>

A low *draught* barge is a barge that can navigate with a high *load factor* in relatively low river depths. The term is usually given to Rhine-faring barges that have a (empty) draught of less than 2 meters when unloaded. The empty draught of a vessel is the distance between the water surface and the keel of the vessel when completely unloaded with cargo and fuel. The empty draught is determined by the material the vessel is made of and the amount of water it displaces (*Riquelme Solar, 2012*). This means that the draught can be calculated by applying the *Archimedes' Principle*. In their study, *van Dorsser et al. (2020)* show that barges with low empty draughts are less vulnerable to LRD than barges with high empty draughts (see *Figure 5.1*). Decreasing the empty draught of the barge will increase its *deadweight* in cases where draughts are already reduced *(van Dorsser et al., 2020)*.

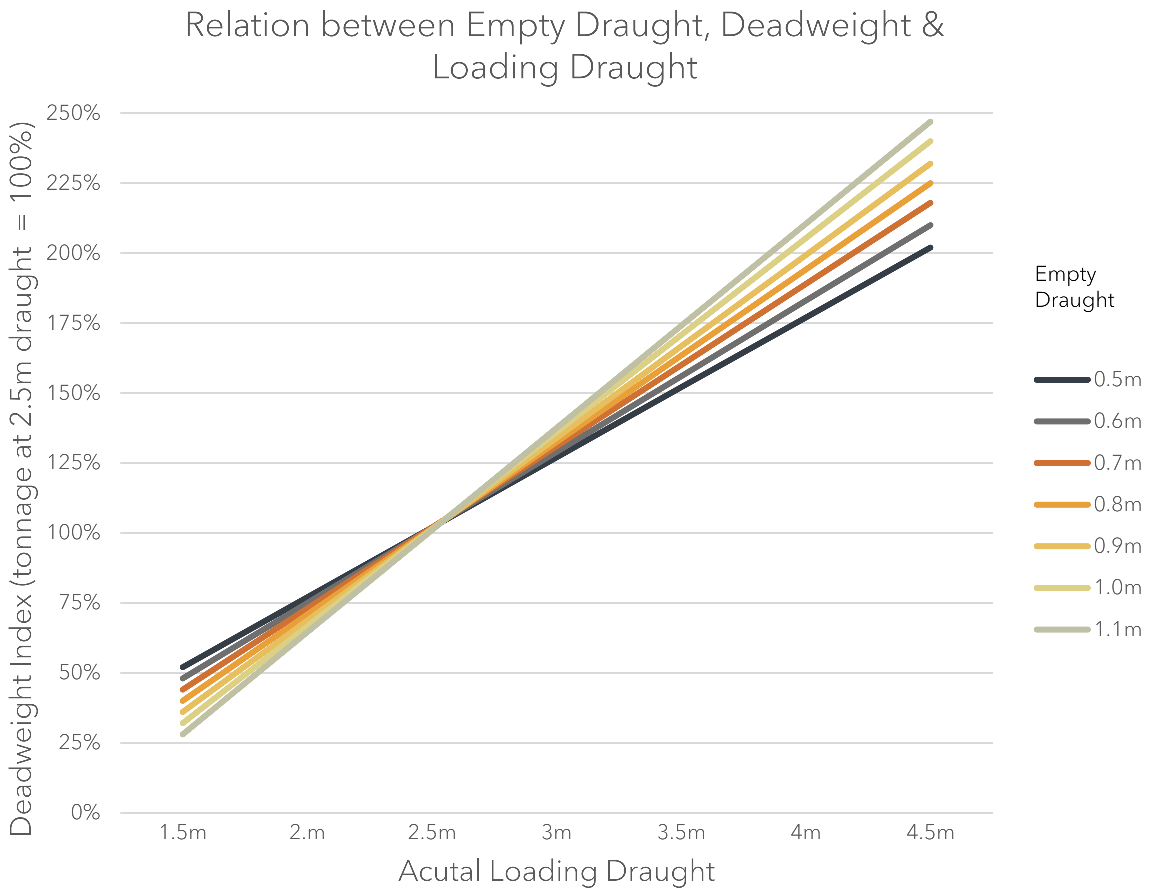

Figure 5.1 | Relation between empty draught and deadweight
(van Dorsser et al., 2020)

The aim when building a low draught barge is to build a wider, shallower, and lighter barge (*Riquelme Solar, 2012*). To build lighter vessel it is necessary to either find lighter build materials or build the barge out of less material (*Krekt et al., 2011*). Currently, barges are exclusively built out of steel. *Blaauw (2009)* has previously proposed the possibility of building barges out of lighter composite materials, however, this has been argued by stakeholders in the IWT sector as being unattainable due to the expense of the materials (*LSP.1*). It is also possible to build a barge with less material at the cost of the structural integrity of the barge (*SK.2*).

While it may be possible to decrease the draught further, other considerations come into play, such as the need for enough draught for the propeller to catch enough water flow required for efficient propulsion. Currently, traditional propeller installations on barges require enough depth to provide sufficient water flow to produce thrust and, therefore, limit draught reductions to 1.4 meters for small barges and 1.85 meters for large vessels (*van Dorsser, 2015*). New designs have proposed the use of multiple motors that require smaller propellers to produce the same amount of power (*LSP.1*), which would reduce the need for more draught. Other design work on the placement of motors towards the side of the vessel or changing the *propeller tunnel* to direct more water flow to the propellers (*Heynen, 2011*).

Building barges with a larger *beam* can increase the capacity of a barge without increasing its draught (*TAB.1*). However, operating wider barges is often troubled by the fact that wider barges have cannot fit into all sluices. Currently, sluices are built to a specific width to accommodate specific *CEMT-Classes* of barges (*Koedijk, van der Sluijs, & Steijn, 2017*). While the Rhine is classified as a Class VI waterway, meaning it can accommodate barges up to 22.8 meters in width, its tributaries and distributaries are only classified as Class V (11.4 meters in width) (see *Figure 5.2*) (*Koedijk et al., 2017*). This means that increasing barge beams beyond 11.4 meters will inhibit access to important Rhine tributaries and restrict navigation to the Rhine year-round.

Figure 5.2 | Map of CEMT-classes of Rhine and main (dis)tributaries
(United Nations Economic Commission for Europe, 2012)

<u>Fleet Diversification</u>

While a barge's draught can be compensated by its beam and length to attain an equivalent load capacity, wide and long barges have trouble accommodating various smaller waterways (see *'Low Draught Barges'* on *page* 52). A way to combat this issue is by having a diverse fleet. By also incorporating smaller vessels into a fleet, it becomes possible to keep servicing destinations located on smaller waterways.

A Class III barge, for instance, has a minimum empty draught of 1.50 meters compared to 2 meters of a Class VI barge, which are typically used for transport on the Rhine (*Koedijk et al., 2017*). When fully loaded their draughts increase to 2.70 meters and 4 meters respectively (*Koedijk et al., 2017*). While smaller Class III barges generally have a quarter of the deadweight of Class VI barges, this advantage is reduced during LRD periods (*Bosschieter, 2005*). During an LRD period of, for instance, 2 meters of river depth, a Class VI barge is restricted to 46% of its deadweight, while a Class III is still able transport 65% of its original deadweight (see *Figure 5.3*). This discrepancy makes deploying smaller vessels more efficient than large vessels during LRD periods.

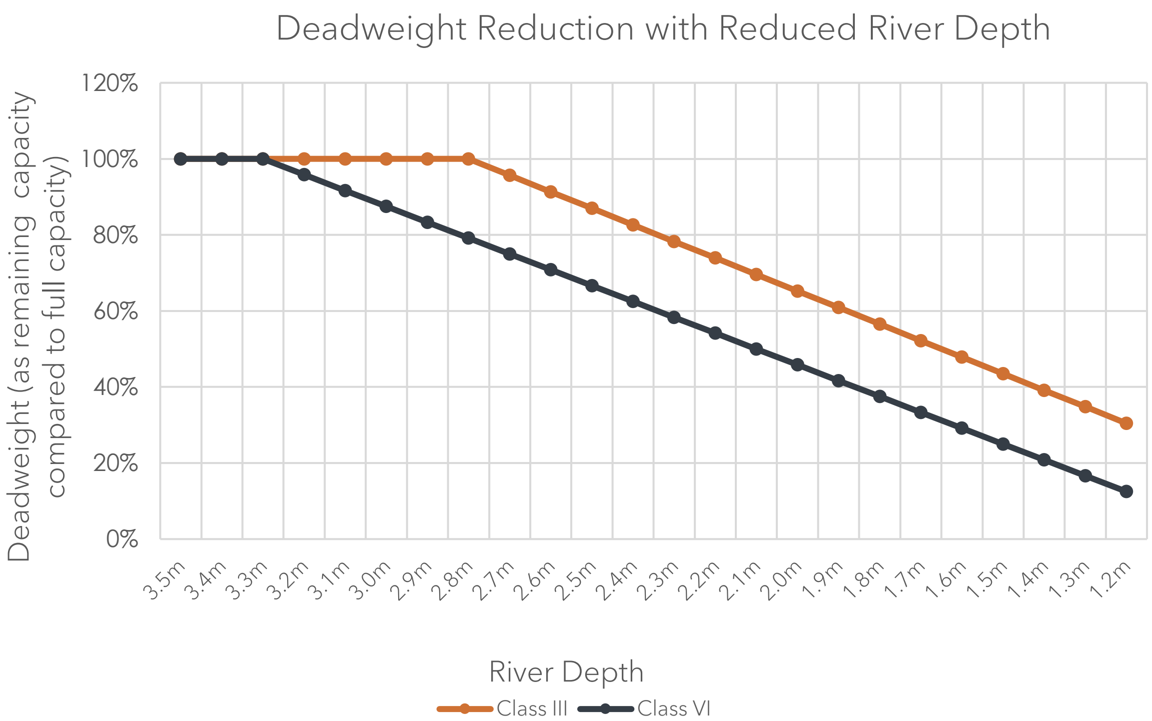

Figure 5.3 | Deadweight reduction with low river depth
*(*Bosschieter, 2005*)*

The disadvantage of using small vessels needs to be mentioned in the discussion of using smaller vessels. The reason why large Class VI vessels are used instead of smaller Class III barges is that a larger barge carries advantages due to economies of scale (*SK.2*). The increase in deadweight offered by larger vessels is relatively large compared to the increase in costs of additional crew members and supplementary fuel costs (*Ypsilantis & Zuidwijk, 2013*). Although losing benefits of scale, a fleet of smaller vessels can be autonomized to save on operational costs. However, if digitalization and automation trends continue, it possible to think that less crew is needed to staff a vessel, which would reduce the costs of running a ship (*LSP.1*).

The disadvantage of smaller vessels can theoretically be dealt with by only using smaller vessels during periods of LRD. A representative from a logistical IWT service provider explains that during LRD periods, his company previously deployed smaller vessels on the Rhine (*LSP.1*). These vessels normally operate on smaller channels throughout period without LRD but can temporarily substitute for large barges that are inefficient during LRD periods (*LSP.1*). The large vessels were able to be used between Rotterdam and Antwerp or in the Netherlands and Belgium, where LRD is less of a problem (*LSP.1*). Having multiple services on different types of waterways ensured that this logistical service provider was able shift vessels to satisfy the conditions and demand (*LSP.1*). The added flexibility that a diverse fleet provides could be considered a measure that IWT businesses can implement when contemplating deploying smaller vessels.

Pushed Barges

Pushed barges are relatively less sensitive to decreases in river depth due to their reduced empty draught when compared to their motorized counterparts. A pushed barge is built relatively light due to the lack of a motor, fuel tanks, and bridge. This enables a pushed barge to have a reduced empty draught with respect to motorized barges (*Koedijk et al., 2017*). As a logistical service provider explains, during periods of LRD, pushed barges can allow for an optimal configuration that combines the need for economies of scale and the reduced draught needed to navigate during LRD periods (*LSP.1*).

The disadvantage of pushed barges come in the form of a lack of flexibility. Barges that are specifically built to accommodate pushed barge shipping always needs to navigate with a pushed barge due to their flat bow that enables them to push pushed barges more efficiently. Without the added pushed barge to form a rounded bow, pusher barges have a flat bow, making passing through water less efficient. Pusher barge navigation without pushed barges is therefore limited to short distances between various pick-up and drop-off locations (*SK.2*).

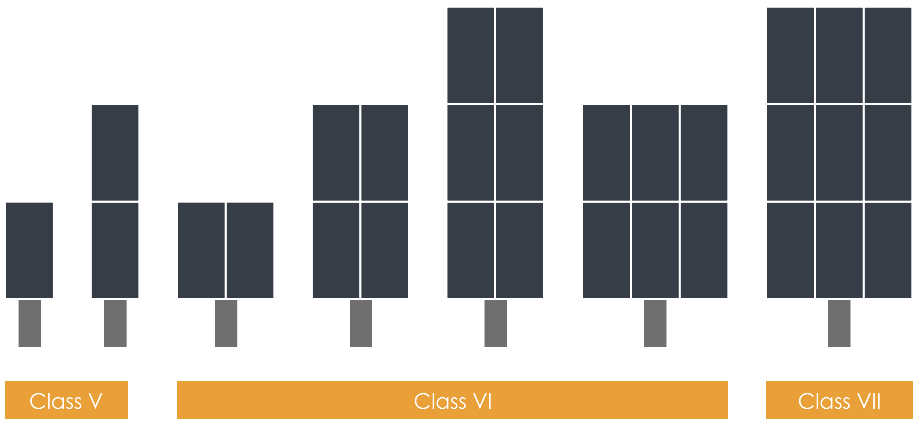

Figure 5.4 | Pushed barge configurations and CEMT-Class (blue: pushed barge; grey: pusher barge)

However, not all pushed barge *convoys* have pusher barges with dedicated flat bows. Although this makes navigation in convoy less efficient, pusher barges have more flexibility. Many motorized barges can temporarily act as pusher barges and navigate with different configurations of pushed barges (see *Figure 5.4*). This allows a standard motorized barge to temporarily increase its loading capacity without increasing its draught. The problem with larger pushed barge convoys is that they cannot access all (dis)tributaries due to larger convoys exceeding the CEMT-Class conditions (see *Figure 5.3* and *Figure 5.4*).

5.1.2 Logistic Management

By changing the logistics of transport services, it is possible to increase the flexibility and redundancy in transport services. Logistic management covers all the internal measures that make changes to the route and mode of transport over which goods are transported from origin to destination. Other logistic management practices that cover the storage of goods are not in the direct control of IWT carriers and are therefore not considered in this list.

Alternative Routing

A logistical way of adapting to LRD periods on the Rhine and Waal is to simply not use the Rhine and Waal. The Lek and Meuse Rivers provide alternatives to the Waal in the Netherlands. While the Waal can experience LRD due to a regional drought, the Lek and Meuse are canalized waterways and therefore are less affected by droughts. Locks in the Lek and Meuse regulate the river flow and depth, thereby enabling navigation under less extreme condition relative to the Waal. Alternative routing through the Lek and Meuse can therefore be considered a possibility to reach destinations further inland *(van der Beek & Westebring, 2020)*.

Although the Meuse and Lek do not reach into the German *hinterland*, transshipment onto other modes of transport can be conducted at inland terminals such as the Europe Container Terminal in Venlo when transporting via the Meuse.

The limits of the Nederrijn (an extension of the Lek) and Meuse come in the form of the capacity of the locks. Locks at Grave and Lith have a maximum number of vessels that can pass daily and restrict the dimensions of barges to Class V (110 meters x 11.40 meters) or smaller (see *Figure 5.5*). This capacity restriction renders the Meuse a less viable alternative route (*van der Beek & Westebring, 2020*). According to representative of an inland shipping sector association, infrastructural upgrades to the locks would be needed if throughput capacity is to grow (*ISA.1*).

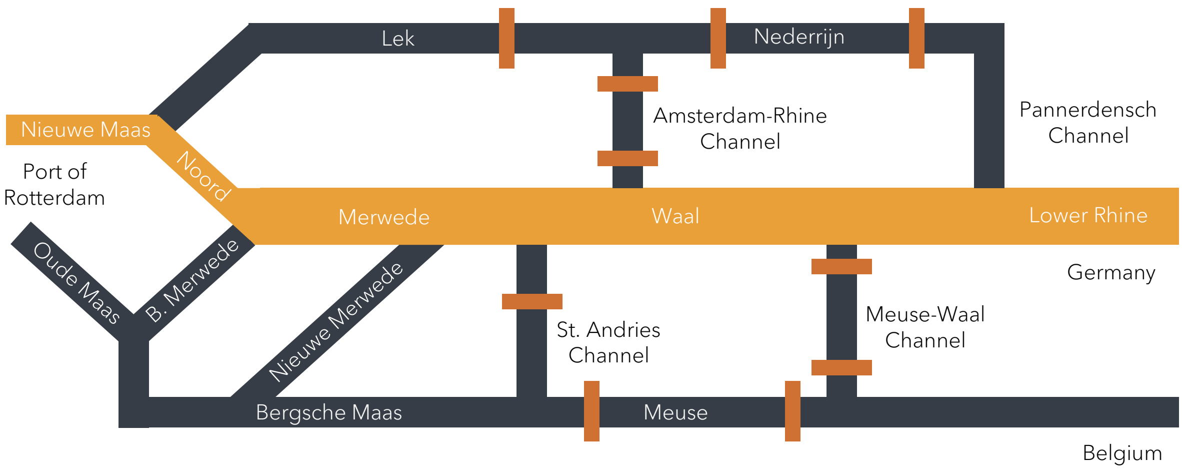

Figure 5.5 | Alternative routes to the Waal via Lek and Meuse
(orange: Rotterdam-Rhine corridor; blue: smaller waterways; orange: sluices)
(van der Beek & Westebring, 2020)

Synchromodality and Intermodal Transport

Making use of other modes of transport can offer logistical ways of adapting to LRD periods. Generally, this can be done in two ways. Either other modes of transport such as road transport or rail transport are kept as reserve services for highly time-sensitive freight (*synchromodality*), or other modes of transport are used to supplement IWT on parts of the river that are most affected by LRD (*intermodal transport*).

Synchromodality can provide a way of absorbing regular streams. Having reserve capacity on rail service or possessing a fleet of trucks can allow time-sensitive goods to be transported to their destinations on time. Currently, a large logistical IWT service provider offers synchromodal services for their container transport services (*LSP.1*). This allows them to continue offering transport services in the event that one or the other service is down (*LSP.1*).

Intermodal transport refers to transport that uses multiple modes of transport to transport the same load of freight to a single destination. In its purpose as a measure against LRD periods, intermodal transport serves a different purpose than synchromodal transport. By making use of multiple modes of transport it is possible to remain transporting via IWT on sections of the Rhine and Waal that are still navigable. Furthermore, as mentioned above, intermodal solutions can be used in combination with alternative routing to make use of other river infrastructure in cases when the Waal suffers from LRD. A representative from a Dutch logistical IWT service provider explained how his company offered such solutions during the drought of 2018 (*LSP.3*). He mentioned that the *inland port* at Venlo functioned as a transshipment hub for placing freight from IWT on the Meuse onto trains heading for destinations in Germany.

5.1.3 Data Management

When providing logistical services, information is necessary to know what to transport and how to transport something economically. The current wave of computing innovation can provide solutions to adapting to more frequent, severe and time extensive LRD periods. Innovative information management practices will increase IWT businesses' visibility with regards to LRD periods, which allows them to anticipate demand for their services and navigational conditions and adapt their services accordingly.

<u>River Depth Forecasting</u>

Before departure, skippers use weather forecasting and intuition to predict the river depth of the segments of the Rhine that they will be travelling on (*SK.1; SK.2*). During LRD periods, this practice allows skippers to accurately load their barges to the predicted river depth so that they can maximally utilize the available river depth.

This practice can theoretically be expanded to allow for better prediction of river depth to better plan when the ideal conditions are within a given time frame. This, however, requires more than simple weather forecasting and skippers' intuition. Models that can predict river hydrology with input from long-term weather forecasting could allow IWT businesses to plan shipment ahead or after of suboptimal navigational conditions so that contractual obligations with shippers can still be fulfilled.

Currently, river hydrological models can predict when LRD periods will occur a few weeks in advance (*Bakke et al., 2020*; *Ionita & Nagavciuc, 2020*). EFAS, a model developed by the Copernicus Emergency Management Service, was for instance able to predict the extreme LRD period of 2018 six weeks ahead (*Emerton, 2018*). If IWT businesses applied this information in their planning and communicated this with shippers, inventories could have been stocked and raw material sites could have been emptied beforehand.

Real-time Data on Riverbed

During LRD periods, the river depth needs to be factored in the *loading draught* when calculating how much deadweight a barge can transport. Currently, skippers rely on measurements by *river gauges* at sporadic locations on the Rhine to interpolate the current river depth over the entire Rhine. Skippers factor in weather reporting to estimate the development of the river depth at their time of arrival. Safety margins (usually 20-30cm) are added onto the measured data at the river gauge due to possible changes in weather forecasting and unevenness in the *fairway* due to sandbank accumulation.

By adding river depth measurement devices to individual barges and collecting the data in real-time, an accurate picture of the riverbed can be created and made available to skippers (*van Middendorp, 2020*). The precision of data allows skippers load a barge to closer to its maximum capacity as safety margins can be reduced. Real-time knowledge of the river depth at all locations in the river and precision weather forecasting and river flow modelling can allow skippers to know how to load their barges more precisely. This can increase the deadweight of a ship by reducing the safety margins traditionally employed due to the lack of knowledge on exact river depth along the river.

Furthermore, real-time data can improve knowledge on the positioning of the navigational fairway. This would allow skippers to make more use of the width of the fairway and increase navigational speeds during LRD periods. Navigability can thus be improved by providing up-to-date data on current and expected water depths in the fairway, expected bed topography (*Krekt et al., 2011*). This data would improve estimated time of arrival data that can be used to optimize intermodal transport connections (*Hekkenberg, van Dorsser, & Schweighofer, 2017*).

Lastly, data on the riverbed that is continuously updated can serve as an input into the river hydrological forecasting models mentioned *above*. After a common high flow period during the winter months, the riverbed can change as sediment is carried downstream by the large kinetic force of the river (*Spreafico & Lehmann, 2009*) (*SK.2*). Updated information on the riverbed can improve the accuracy of river hydrological models.

Vendor Managed Inventory

Although not commonly deployed in the IWT sector, vendor managed inventory can offer solutions to prepare for incoming LRD periods. Current technology can predict LRD periods as far as six weeks in advance, thereby signalling to *shippers* that there may be restrictions to goods delivery up ahead.

Vendor managed inventory is a supply chain agreement between a shipper and an IWT carrier, in which the IWT carrier takes on the responsibility of inventory management for the shipper. By providing data on current inventory at destinations, IWT carriers are given the responsibility of maintaining an agreed upon minimum and maximum level of inventory. IWT carriers often have the better knowledge on how they can transport goods under what conditions and are therefore more suited to making decisions on when and how goods should be transported.

Vendor managed inventory practices require long-term contracts between shippers and IWT carriers and a level of trust with regards to the privacy on data that is shared on the shipper's inventory. A representative from a logistical service provider explains that his company uses VMI to great success, but that these contracts are very rare currently due to the required level of trust needed to sharing data openly and off-loading a crucial part of logistical management to another party (*LSP.3*).

Key Findings of Chapter 5

1. IWT businesses can increase their climate adaptability by making alterations to fleet, logistical and data management

6 Analysis

SQ 4

What internal climate adaptation measures can robustly safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (R)

Now that the Dutch IWT sector's objectives, the external developments facing the sector, and the internal measures available to the sector have been established, a systems diagram links these three elements. This chapter relates these three elements to each other by providing an answer to how the external developments and internal measures can possibly influence the targeted objectives. Information on these links is provided through the interviews conducted with the various stakeholders of the Dutch IWT sector. Ultimately, this chapter aims to provide an understanding of the theoretical effects of different internal measures on the objectives of the IWT sector and understand their robustness in the context of external developments. This will showcase how the IWT sector can possibly safeguard their long-term viability.

6.1 Systems Model

As was mentioned in the subchapter on '*Systems Modelling*' on *page 27*, systems modelling (i.e., systems diagramming) is meant to be used as a tool to clarify the effects of the internal measures on the long-term transport viability of the Dutch IWT sector (*Quade, 1980*). This subchapter presents the systems models and uses them to present and explain the effects of internal measures.

These systems diagrams and the insights they produce are the product that is presented to various stakeholders during evaluation interviews.

6.1.1 Systems Behaviour during LRD Periods

The figure *below* shows an influence diagram (i.e., systems diagram) of the various factors that influence profits in the Dutch IWT sector. The understanding of the relations between the factors depicted in the influence diagram is established from the interviews with 17 different stakeholders of the Dutch IWT sector. The influence diagram ultimately shows how various external developments and internal measures affect the profit of the IWT businesses (see *Figure 3.1* for a detailed view of how IWT price, IWT demand and IWT costs affect profits).

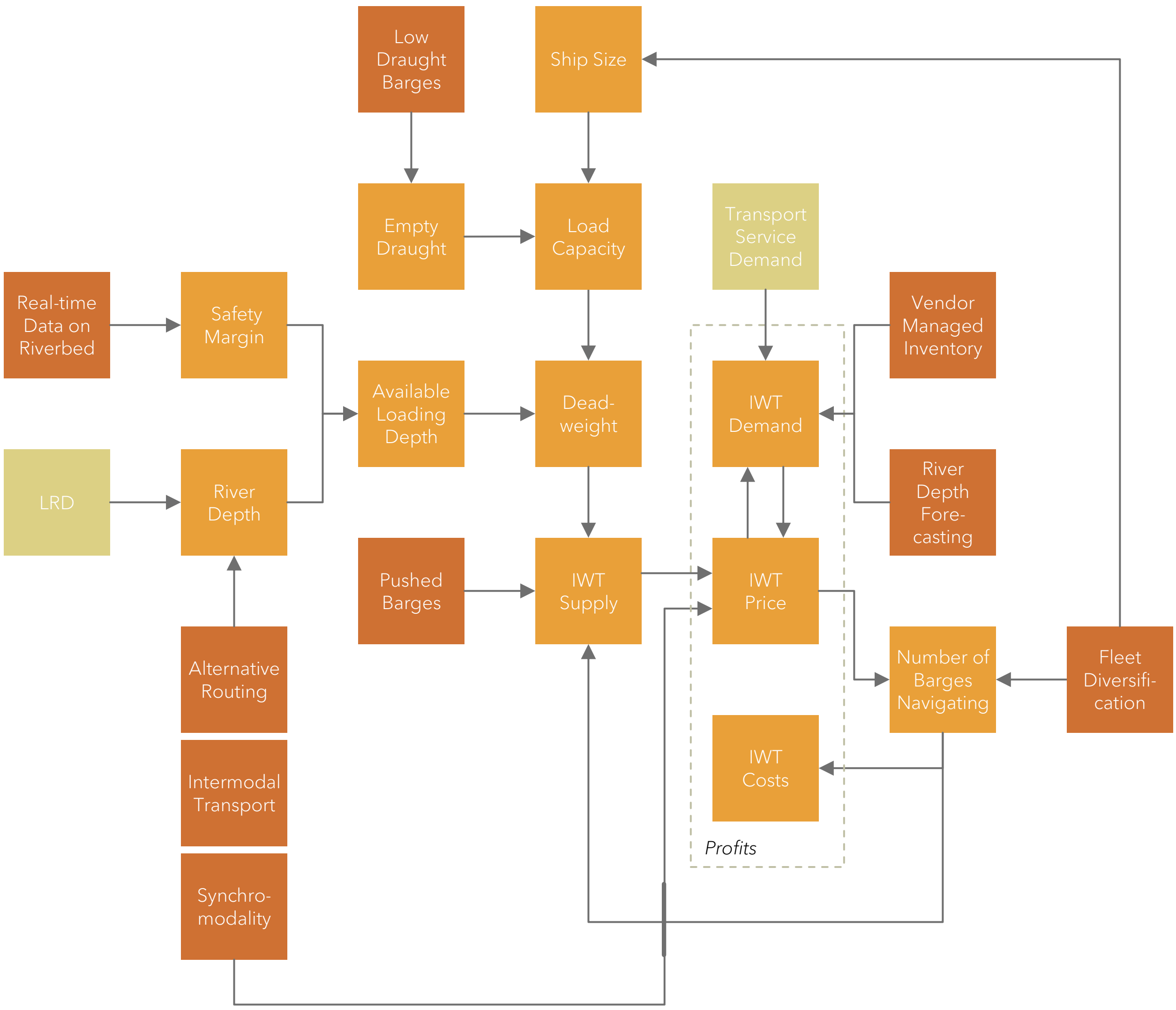

Figure 6.1 | General influence diagram

The influence diagram shows in detail how the manifestation of LRD periods and transport service demand influence the profits of IWT businesses. As river depth is lowered during an LRD period, skippers are left with less loading depth on their barges and thus must reduce the deadweight caried. This has the effect of reducing the overall IWT supply available on the market which increases the IWT price. In reaction to the increased IWT price, more barges will navigate or more barges navigate longer hours at that price which will slightly increase the IWT supply and lower IWT prices. This way, the IWT price will balance out to an equilibrium. Adding additional barges to transport equivalent amounts will increase costs (see *Figure 6.2*), especially since crew costs will increase relatively quickly as the market for crew members is tight (see *'Effects of External Developments'* on *page 63*). This increase in IWT costs will cut into the profits of an IWT business.

In the systems diagram, a distinction is made between load capacity and deadweight. The total capacity of barge is determined by its size (beam x length x draught) and its empty draught. The lower the empty draught, the more a barge can load in terms of tonnage. Since LRD lowers the loading draught of a barge, a barge can transport less tonnage than without this restriction. The tonnage that a barge can transport under specific conditions is called deadweight.

6.1.2 Effects of External Developments

In a more detailed view of the General Influence Diagram above, Figure 6.2 shows how the combination of LRD periods and a shift in transport service demand can influence IWT profits. As the IWT price during an LRD period increases because heightened IWT demand requirements and decreases in IWT supply capacity, more skippers will be pulled into the market and deploy their barges during the LRD period. These barges are not regularly deployed for goods transport on the Rhine because they often lack the size to provide economies of scale, which is common shipment on the Rhine. However, high prices and contractual obligations can make it worth or necessary to deploy more inefficient barges to transport goods during LRD periods. Ultimately, this inefficient deployment of barges increases the full costs per tonne-kilometre. Additionally, the increased IWT price and/or contractual obligations incentivize longer deployment of the barges that are purposed for regular Rhine transport. Some skippers will choose to navigate for longer hours or set up 24 hour per day services in collaboration with two other skippers to optimize the time deployment of their barges during LRD periods. This, however, usually means paying higher prices for crew members as a definite supply of IWT crew means inhibits IWT businesses from attracting more crew member indefinitely. Ultimately, schemes that prolong the operational hours of a barge therefore increase the crew costs per tonne-kilometre.

Although the higher IWT prices can justify these inefficient practices, the overall costs of an IWT businesses also rise. As long as the IWT price rises faster than the IWT costs during an LD period, IWT businesses can still make a profit in the short term (see *Figure 6.2*). Due to the added low water surcharge, the IWT price always rises faster than the IWT costs. While some contracts allow shippers to postpone shipments for a few weeks during LRD periods, the duration of an LRD period beyond what shippers can compensate with added inventory can force shippers to pay high IWT prices. In relation to bulk transport shipment, container transport shipments are more time-sensitive and cannot be postponed. Due to the unrelenting of demand for container shipment during LRD periods, IWT prices for container shipments will rise further than IWT prices for other goods.

In cases of intense LRD periods, many barges can be physically hindered from navigating to certain destinations regardless of the price shippers are willing to pay. If IWT businesses cannot deliver for an extended period (i.e., more than one month), some shippers will choose other modes of transport (*Meijeren et al., 2011*). Depending on a shipper's dedication to IWT in their supply chain, some shippers are left with no other choice but to deal with shortages in their production materials or overflows at their raw material sites during lengthy LRD periods (*Meijeren et al., 2011*).

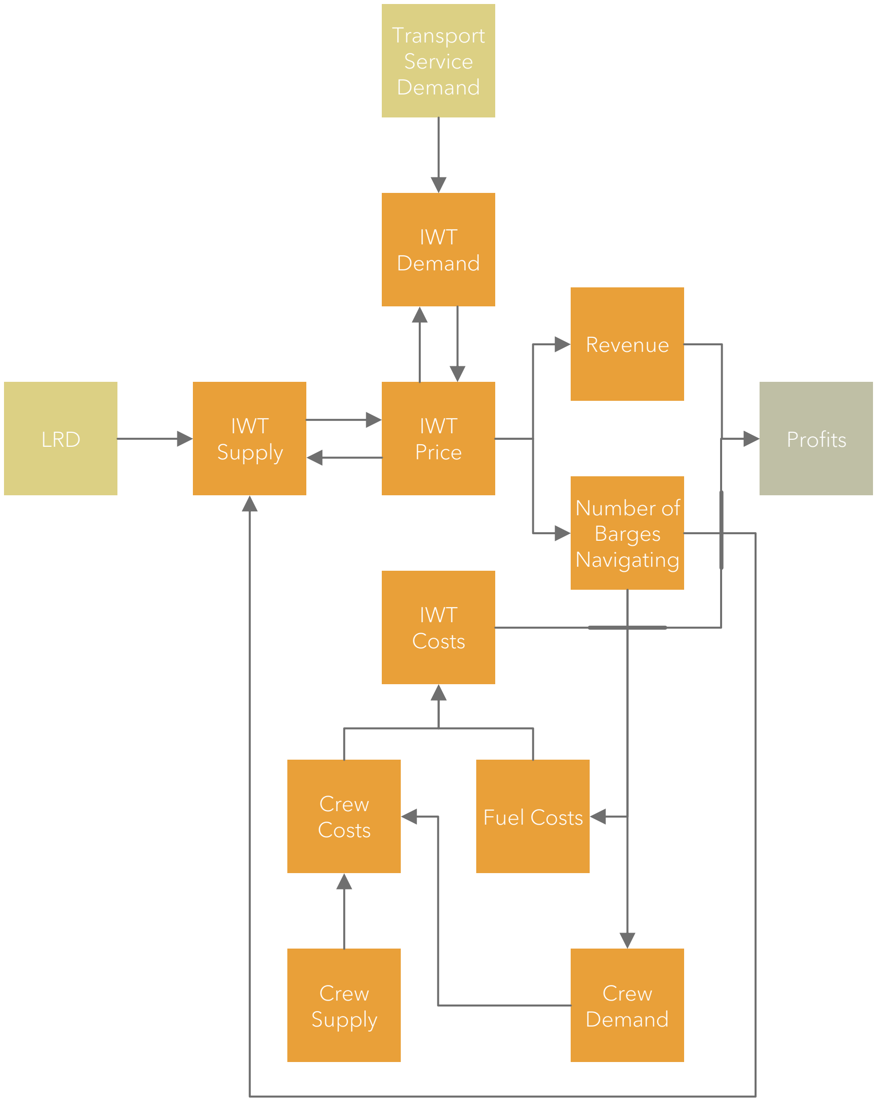

Figure 6.2 | Effects of external developments on profits

While intense and time-extensive LRD periods and a shift towards less flexible container transport will increase profits for IWT businesses in the short term, this does not yet account for the long-term effects such developments have on the IWT sector. In the long term, high IWT prices and a lack of reliability can weaken the reputation of the IWT sector as a reliable transport partner (*SHTA.1*). If IWT businesses are not able to offer a certain amount of guarantee of on-time shipment, shippers will either be forced to increase their inventory capacity, move locations, or choose other modes of transport to make their supply chains more robust (*Meijeren et al., 2011*). In the future, shippers might be less willing to put faith in the IWT sector as a price competitive and reliable means of transporting their goods. This could ultimately threaten the long-term IWT demand viability (see *Figure 6.3*).

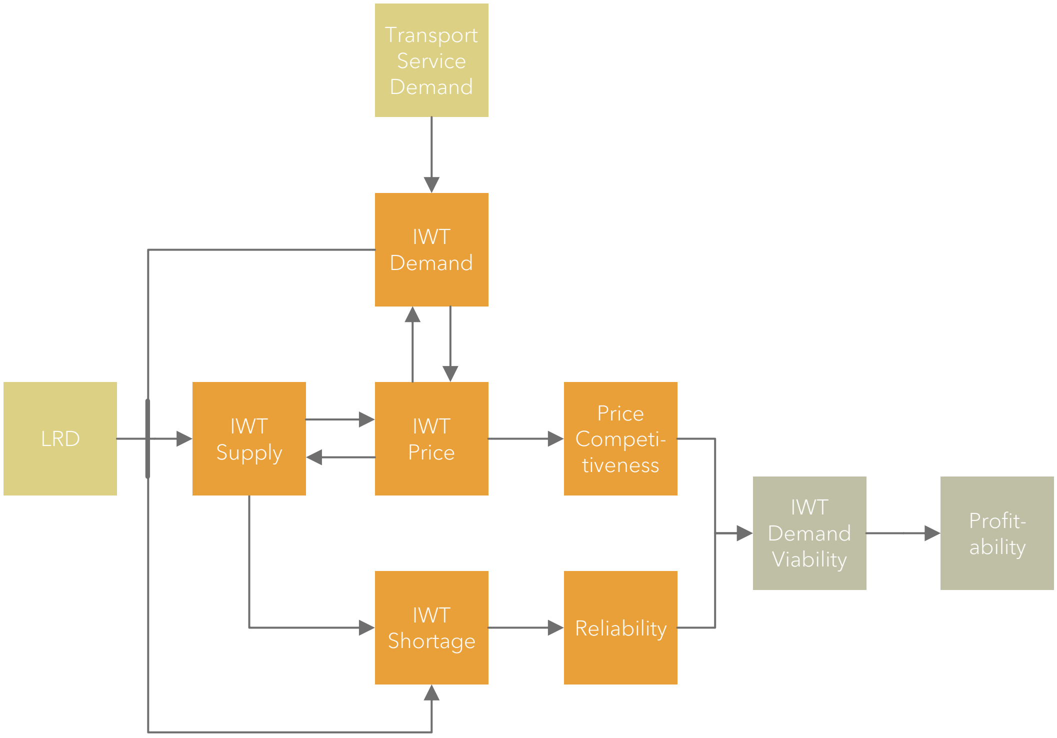

Figure 6.3 | Effects of external developments on viable IWT demand

6.1.3 Effects of Internal Measures

In the subsections that follow, the influence of internal measures on the IWT sector is elaborated on.

<u>Fleet Management</u>

In the influence diagram (see *Figure 6.1*), three fleet management measures are linked. During periods of LRD, these measures can ensure that the price of IWT does not increase sharply. All three measures target increasing the supply of IWT capacity during LRD periods. While all theoretically aiming to do the same, each measure affects the transport supply from a different angle (see *below*).

Table 6.1 | Fleet Management Effects

MEASURE	EFFECT
Low Draught Barges	Decreases the empty draught of barges, which increases the total load capacity of a barge during LRD periods. The main consideration when implementing such a measure is the expenses when constructing low draught barges
Fleet Diversification	Having a more diverse fleet will allow more barges to be deployed during LRD periods, which will increase the transport supply. The consideration when having many smaller barges is that their deployment during non-LRD periods is less efficient than using larger barges due to economies of scale
Pushed Barges	Travelling in pushed barge convoy will add to the overall supply of transport capacity. The main consideration when using pushed barges is what to do with pushed barges during non-LRD periods. Either IWT businesses leave store them for deployment during LRD periods or find creative ways of deploying pushed barges during non-LRD periods

<u>Logistic Management</u>

Internal measures that tackle the logistical operations of IWT during LRD periods can increase IWT businesses' abilities to avoid segments of the Rhine that are affected by LRD periods as much as possible, thereby keeping the IWT price more stable (see *below*).

Table 6.2 | Logistic Management Effects

MEASURE	EFFECT
Alternative Routing	IWT businesses can use alternatives routes to an extent to avoid river segments with low river depth. However, using alternative routes requires barges that are smaller that can fit into the narrower channels. This requires having a diverse fleet
Synchromodality and Intermodal Transport	Synchromodal and intermodal solutions attempt to avoid low river depth segments. The main consideration when using such solutions is that it requires continual expenditures in reserving transport capacity on other modes of transport or long-term investments in upgrades at transshipment inland terminals

Data Management

Using data towards their advantage, IWT businesses can learn to adapt to LRD periods. On the one hand, IWT businesses can use data to load their barges to a greater accuracy during LRD periods or learn to avoid having to service shippers during LRD periods by employing forecasting and planning tools (see *below*).

Table 6.3 | Data Management Effects

MEASURE	EFFECT
River Depth Forecasting	The ability to forecast river depth far into the future allows IWT businesses to ease transport demand during LRD periods. This requires some coordination between IWT businesses and shippers
Real-time Data on Riverbed	The investment in technology that can in real-time provide data on the riverbed can allow skippers to reduce the safety margin that they use when loading a barge. This requires investments in measurement devices and the cooperation of skippers
Vendor Managed Inventory	Working with shippers to manage their inventory can ensure that there is less demand for transport during LRD periods. This requires close cooperation between shippers and IWT business and long-term contracts

6.2 Measure Robustness

In the previous subchapter, an analysis is given on the effects of LRD periods on the Dutch IWT sector. The effects of internal measures are generically explained. However, the previous subchapter does not dive into the robustness of these measures. In this subchapter, an analysis is shown of the robustness of the previously established internal measures with regards to different scenarios of the development of LRD.

When making decisions on which internal measures to pursue to safeguard the long-term viability of the Dutch IWT sector, IWT businesses need to consider how the future will shape the sector. While IWT businesses can design a strategy (i.e., a collection of internal measures) for what they believe to be the most likely scenario, this strategy may have adverse effects on the IWT sector if the most likely scenario does not unfold.

Robust decision analysis looks for strategies that are robust rather than optimal. By using the *XLRM framework,* robust decision analysis considers a wide range of scenarios of different permutations of the unfolding of potential external developments and attempts to satisfy the objectives in the most scenarios rather than optimize for the objectives within one (most probable) scenario.

6.2.1 Trade-offs Under Different External Development Scenarios

To understand the robustness of internal measures under various scenarios, robust decision-making makes use of trade-offs. By comparing the advantages of an internal measure within certain scenarios to the disadvantages it has in others, it possible to characterize the robustness of an internal measure.

This thesis research projects does not intend to provide quantitative insights on the trade-offs of each internal measure but creates a general overview of what trade-offs an IWT business can expect when implementing an internal measure. In the subsections below, four scenarios of distinct manifestations of future LRD periods and the trade-offs they induce are presented. Any shifts towards container transport are generally seen as amplifiers of the effects of LRD period manifestation.

<u>No Increases in LRD Intensity, Frequency, or Duration</u>

In a scenario in which LRD periods do not increase in intensity, frequency, or duration, many of the internal measures taken would have adverse effects on the profitability of the Dutch IWT sector. Mainly due to the large investments of various internal measures, a scenario in which LRD periods play a minimal role causes many of the investments to be seen as wasted. Investments made into the construction of expensive low draught barges, or the retrofitting of current barges are ineffectual. Similarly, any sunk investments made into upgrading inland transhipment ports to accommodate intermodal transportation or any costs of reserving additional transport capacity on other modes of transport are wasted as these facilities and services are not used to their full potential. While sunk costs in developing forecasting models or a riverbed measuring network also do not reap many benefits in this scenario, their costs are relatively minor when compared to the other measures. Additionally, the data from these models can also be useful to understand how river hydrology/morphology impacts navigation during high river depth periods.

Other internal measures harbour less severe trade-offs in a scenario in which LRD periods do not increase in intensity, frequency and duration. For instance, while making barges less maneuverable, IWT businesses can use pushed barges during non-LRD to increase the efficiency of barges. Due to the added transport capacity, pushed barges can offer IWT businesses a flexible way of making use of economies of scale when needed. The trade-off that pushed barges bring occurs when IWT demand is too low to justify using additional pushed barges. The cost of storing pushed barges or the inefficacy of navigating with empty pushed barges can slightly increase costs during non-LRD periods. Additionally, navigating with a pushed barge can make convoys too large to navigate through smaller sluices. However, having a diverse fleet with many smaller barges can alleviate this problem. While only having smaller barges would be disadvantageous during non-LRD periods due to the losses in economies of scale, having a diverse fleet can allow smaller vessels and larger barges (in pushed barge convoy) to work cooperatively. Large barges could fulfill demand on the Rhine, while smaller barges could supply demand on the smaller waterways. Having a diverse fleet would also allow for the use of alternative routing.

The implementation of Vendor Managed Inventory practices has an ambiguous effect in a scenario in which the occurrence LRD periods does not change in the future. On the one hand, being able to work closely with a shipper has benefits regardless of LRD such as being able to plan the logistics of shipment better in advance rather than working on an ad hoc schedule. However, Vendor Managed Inventory require long-term servicing contracts between IWT businesses and shippers. One could make an argument that there are opportunity costs to be accounted for by not being able to switch to service other shippers that may pay more in the long-term.

Increased Intensity

IWT businesses are benefitted by the implementation of all internal measures in a scenario in which the intensity of LRD periods increases compared to recent decades. Although some internal measures are more economically efficient than others, generally speaking, more intense LRD periods warrant more climate adaptation.

Increased Annual Frequency

When adapting to a scenario in which the annual frequency of LRD periods is higher than is today, measures such as river depth forecasting and Vendor Managed Inventory practices would be beneficial. These allow IWT businesses to anticipate which weeks would be affected with LRD periods and plan accordingly. The more often LRD periods occur, the more often such tools would be beneficial. Without the extended duration of LRD periods, other measures are less effective, since IWT businesses can use the forecasting tools to anticipate when to best ship goods.

Increased Duration

Increased duration of LRD periods is the most harmful to the IWT sector as delays in shipment start to become more of an issue with shippers. If LRD periods exceed the planning scope that is provided by river depth forecasting and vendor managed inventory tools, the benefit of these measures will decrease. In this case, more expensive measures are warranted as LRD periods extend over a larger share of the year. Measures involving fleet and logistics management can increase in benefit the longer they are deployed as the investments made reap their benefits.

6.2.2 Summary of Measure Robustness

The table *below* shows the performance of each internal measure relative to the performance of the other internal measures within the same scenario.

Internal measures that require high investments are considered less robust. In general, internal measures that focus on data management and hence have low investment costs are relatively robust. Likewise, the ability to make use of alternative routes also has relatively few investment costs attached and can therefore be considered relatively robust. As mentioned above, combining a diverse fleet with pushed barge capacity can be beneficial during LRD periods and non-LRD periods.

Table 6.4 | Score Card of Internal Measure Performance

MEASURE	NO INCREASE	INTENSITY	FREQUENCY	DURATION
Low Draught Barges	– –	+	+–	++
Fleet Diversification	+–	+	+	++
Pushed Barges	+–	+	++	++
Alternative Routing	+–	+	+	++
Synchromodality and Intermodal Transport	– –	+	+	++
River Depth Forecasting	+–	+	++	+
Real-time Data on Riverbed	+–	+	+	+
Vendor Managed Inventory	+–	+	++	+

Key Findings of Chapter 6

1. IWT businesses profit from more intense, frequent and time-extensive LRD periods in the short as prices are temporarily inflated. A shift towards container transports will strengthen the effect of LRD periods on prices as container transport are more time-sensitive

2. Depending on the intensity of an LRD period, shipments can be delayed. Depending on the duration of an LRD period, the delays become a liability. Depending on the frequency of LRD periods, the liabilities damage reputation

3. In the long term, higher prices and delays in shipment will damage the reputation of the IWT sector as a price competitive and reliable transport partner. This threatens the long-term IWT demand viability

4. Internal measures that involve high investments or high continuous costs are less robust than internal measures with low costs. This means that data management measures can be considered robust due to the low investment costs

5. When combined, the use pushed barge solutions and fleet diversification can become robust to scenarios in which the manifestation of LRD periods is limited and the shift to containers is less pronounced

7 | Evaluation

SQ 5

What is the potential of the robust decision analysis generated as a product of answering SQs 1 through 4 in supporting the IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector?

The research objective of this thesis research project is to evaluate how a robust decision analysis approach would support the decision-making of IWT businesses in their attempt to safeguard the long-term viability of their businesses and the Dutch IWT sector. This chapter provides an answer to the main research question by providing the results of evaluation interviews with three different stakeholders. These interviews are conducted and processed along the method elaborated in the subchapter on '*Evaluation & Validation*' on *page 28*.

7.1 Information Provision

The most basic requirement of any policy analytical activity is to provide information to stakeholders that was previously unknown or uncertain. As mentioned in the subsection on the '*Theory of Validation of Policy Analytical Activities*' on *page 28*, information provision can be measured by understanding the technical validity, informative usefulness and pertinence/timeliness of the analysis. The following subsections present the results provided by stakeholders.

7.1.1 Technical Validity

The technical validity of an analysis related to the differentiation in aspects taken into account, the internal coherence/consistency, and the empirical quality of the analysis (*Hoogerwerf, 1984*). The stakeholders who participated in the evaluation interviews agreed that the relations portrayed in the influence diagram were internally consistent and empirically valid when compared to their expert knowledge (*ISA.1; SK.2*). Furthermore, the interviewed stakeholders agreed that the two external developments were both relevant to the problem and that the long-term viability of the IWT sector mainly depended on the IWT sector's ability to maintain being price competitive and reliable (*ISA.1; SK.2*).

7.1.2 Informative Usefulness

The informative usefulness of an analysis lies in its ability to inform stakeholders with new insights. The influence diagram shown to stakeholders during evaluation interviews was able to neatly convey certain information that was previously unknown to them about the links between external developments, internal measures and the viability of IWT demand, while the results of the robust decision analysis opened stakeholders up to the concept of robust decision-making, which was previously unknown to them (*ISA.1; TAB.1*).

Firstly, the interviewed stakeholders mentioned that they were not "aware" of the benefit of some of the measures would have on the long-term viability of the sector. For instance, stakeholders paused to think why pushed barge strategies were not implemented for often after understanding the robustness of such a measure.

The explanation of the concept of robust measures was mostly received as eye-opening. Stakeholders mentioned that most discussions on LRD ferried between making the sector as climate adaptable as possible and neglecting the issue all together. Understanding that talking in terms of robustness would allow IWT businesses base decision-making on empirical data that attempt to satisfy stakeholders in most scenarios rather than optimize for one scenario. Stakeholders began to realize that focusing only the most drastic measures such as retrofitting older barges to have lower empty draughts or constructing new low draught barges held back conversations on measures that were more robust (*ISA.1; SK.2)*. A representative of an IWT sector association explained that she had been making a similar case against such measures as many IWT businesses are hesitant to take such drastic measures in case LRD periods do not increase in intensity, frequency or duration.

7.1.3 Pertinence and Timeliness

A representative of an inland shipping sector association immediately understood the value a systems analysis had on being able to convey the relations between external developments and long-term viability of the IWT sector. The representative explained that currently too many IWT businesses focus on short-term profits (*ISA.1*). The systems analysis that presented would serve to better explain the need for focusing on the reputation of the IWT sector. According to the representative, this would facilitate collaboration on long-term objectives (*ISA.1)*.

Secondly, a technical advisory bureau representative regarded the scope of analysis to be relevant to the problem of adapting to LRD periods (*TAB.1*). He mentions that many studies focus on the role of the government but rarely do studies scope the research in such a way that IWT businesses are put in the focus. He further elaborates on that research from this perspective is necessary due to the lack of action undertaken by IWT businesses (*TAB.1*). This conclusion is congruent with the remarks from interviewed stakeholders in earlier rounds in which IWT stakeholders who were not problem owners stressed the need for the need for research on how to get IWT businesses to take action (*PR.1*; *GA.1*).

While the stakeholders interviewed during the evaluation interviews made a point about action not being needed immediately, they did agree that this was a long-term issue (*ISA.1*). A skipper mentions that much of the attention that is currently centred around LRD periods since the LRD period during 2018 can be described as alarmism and that too much focus is put on expensive measures (*SK.2*). He therefore supports making decisions based on robust decision analyses as these account for the uncertainty of long-term external developments and prevent reactionary behaviour based on a singular manifestation of LRD period (*SK.2)*.

7.2 Facilitation of Participative Policymaking Process

The second evaluation criterion this thesis research projects uses to evaluate the potential of the systems analysis is its ability to facilitate a participative policymaking process. While insights can be communicated on an individual basis to different stakeholders, a systems analysis can also be used to communicate between stakeholders.

7.2.1 Inclusiveness

The diversity of the interviewed stakeholders was deemed by the stakeholders interviewed during the evaluation interviews to have added to the overall inclusiveness of the internal measures and their trade-offs presented.

While stakeholders participating in the evaluation interviews acknowledged and understood that the exclusion of measures beyond the control IWT businesses was done deliberately to focus on the measures that IWT businesses could take, they also expressed interest in expanding the inclusiveness of measures from all stakeholders. This shows how the systems analysis can be expanded to include more stakeholders and be used as a tool to combine the measures of multiple different stakeholders.

7.2.2 Communicative Usefulness

The fact that the three different stakeholders were able to understand the influence diagram with relative ease proves to an extent its ability to communicate to different stakeholders.

A representative of an IWT sector association mentioned that this influence diagram can be used as a tool that standardizes the agreed upon knowledge on the IWT system between different stakeholders (*ISA.1*). She explained that standardized schemes are necessary when leading discussions between different parties within the sector as they provide the necessary basis of agreed upon information that is necessary in negotiations.

Furthermore, this tool could be used as an educational device. By painting a clear picture of the sector and how robust measures work, the systems analysis is able to convey the benefits of specific action. A representative of an IWT sector association explains that she can use the findings from a systems analysis to justify the need to invest into measures that are identified as being robust.

7.3 Verification

During the brief evaluation interviews, time was spent on verifying the technical integrity of the systems analysis. The results portrayed in Chapter 6 are therefore iterated versions of the systems analysis that was presented to stakeholders during the evaluation interviews.

Most improvements of the systems analysis were directed on the links between the internal measures and the remaining system. Previous versions of the systems analysis incorrectly mentioned that having smaller barges would be beneficial during LRD periods, while forgetting to mention that having number of large barges was also important. The

Furthermore, some simplifications of the systems diagram were made. Stakeholders remarked that the systems diagrams were at first difficult to follow due to the number of factors integrated into the diagram (*TAB.1*). Adjustments were made to simplify the cost dynamics and remove the link to the profitability. According to another stakeholder that viewed an iterated version of the systems diagram, it was clearer than the one shown to others before (*ISA.1*).

Key Findings of Chapter 7

1. The influence diagram has been deemed to be empirically valid by stakeholders. They mention that the influence diagram can serve as a standard communication object that has the potential to improve the consensus on the common understanding of the impact of the future navigability of the Rhine on the IWT sector

2. The robust decision analysis sparked interest from the interviewed stakeholders as a new method of decision-making. Its value was recognized in its ability to provide information on the trade-offs between measures under different scenarios

8 | Discussion

This chapter reflects on the results from *Chapters 6* and *7*. It provides an interpretation of the results, elaborates on the implications the results have for scientific research and puts the results in the context of the long-term viability of the Dutch IWT sector and the Dutch *modal shift* ambitions. Furthermore, this chapter reflects on the methods used to produce the results and discusses the limitations they cast on the interpretation of the results.

8.1 Interpretation of Results

8.1.1 Robust Trade-offs

The robust decision analysis provided results that are more suggestive than conclusive. The results of the analysis suggest that there are trade-offs between internal measures when regarding that the external developments that impact the IWT sector are uncertain. This justifies the execution of further research that quantitively determines the trade-offs between internal climate adaptation measures. For IWT stakeholders, the fact that the robust decision analysis shows that internal measures vary in their robustness towards different future scenarios, implies that there is value in analyzing the robustness of internal measures before making decisions on investments into certain measures.

8.1.2 Stakeholder Evaluation

Evaluation interviews were intended to provide answers to the main question. This thesis research project used a framework for evaluating policy analytic activity and consulted the opinions and judgement of IWT stakeholders in the process. From the stakeholder evaluation, the influence diagram showed its potential to serve as a standard communication object that could improve the consensus on the common understanding of the impact of the future navigability of the Rhine on the IWT sector. The robust decision analysis sparked interest from the interviewed stakeholders as a new method of decision-making. Its value was recognized in its ability to provide information on the trade-offs between measures under different scenarios.

8.2 Academic Implications

The academic implications of this thesis research project are mainly centered on the contribution it has to the understanding of how robust decisions analyses can be used in the IWT sector. Previously, there has been little research conducted a) to study the long-term viability of the IWT sector from a robust decision perspective or b) to evaluate the usefulness of a robust decision analysis in the decision-making of IWT businesses. Additionally, little focus has been diverted to understanding the decision-making perspective of an IWT business. The developed methodology involving systems analysis and interviewing techniques has been effective for the achievement of the research objectives.

In the subsections below, the implications of the results of this thesis research project are elaborated on in detail.

8.2.1 Robust Decision Analysis from IWT Sector's Perspective

In most preceding academic literature, single measures were explored on their ability to deal with LRD periods. Several studies focused on the technical innovations such as low *draught* barges (*van Dorsser et al., 2020*), river depth forecasting tools (*Ionita & Nagavciuc, 2020*) and specific river training projects (*Havinga et al., 2006*). However, few studies explored what the effect would be on the long-term viability of the IWT sector. Such a research objective requires a look into how such measures would interact with the IWT system under different scenarios of LRD. Academic research from the perspective of entities operating in the IWT sector had been limited (*Riquelme Solar, 2012*). By including the expert judgement from various stakeholders in the production of the systems analysis it was possible to develop a product that represented their perspective.

The systems analysis that was produced as part of this thesis research project was able to show how various internal measures had varying effects on the long-term viability of the IWT sector under different LRD scenarios. The systems analysis ultimately was able to conclude that some measures were more robust to different scenarios than others. These insights are useful to future researchers deciding which specific measures to research in order to safeguard the long-term viability of the IWT sector.

Although the main objective was not to produce a fully-fledged systems analysis, this thesis research project has made the effort to have the systems analysis be verified by experts in the IWT sector for the accuracy of the results it provided. This allows future research on specific developments or measures to use the provided systems analysis to place their findings in a wider context of the long-term viability of the IWT sector.

<u>Discovery of New Knowledge Gaps</u>

While not a research objective of this thesis research project, specific knowledge gaps with regards to singular measures have been pointed out. By performing desk study on the various internal measures and discussing these with multiple stakeholders in the IWT sector, some internal measures were found to have been researched more than others. For instance, this thesis research project has found that the use of pushed barges has not been thoroughly studied. While this thesis research project has alluded to the theoretical potential of using pushed barges, not much research has been conducted to back these claims. Stakeholders in the sector have also expressed their interest in researching this measure as they attest to the fact that this measure has been insufficiently researched.

Another area of interest that can provide further research is the link between fleet diversity and the benefit to climate adaptability of the IWT sector towards LRD periods. This thesis research project has claimed that a diverse fleet theoretically has a benefit, however, stakeholders in the sector have placed question marks around the practical implementation of such a measure. All but one stakeholder has mentioned that they have a limited experience of seeing a diverse fleet be an advantage during LRD periods.

Furthermore, this thesis research project has been able to verify that there is a great interest in developing better forecasting tools.

8.2.2 Robust Decision Analysis in Decision-Making of IWT Businesses

The main objective of this thesis research project was not to simply produce a systems analysis of the IWT sector but understand what its potential was in providing IWT businesses more context for their decision-making with regards to LRD. By relaying the systems analysis back to stakeholders, a clear understanding of how systems analyses could benefit stakeholders was established. The previously hypothesized benefit of being able to understand the trade-offs between implementing internal measures was proven to exist. Stakeholders reacted positively to the produced systems analysis by elaborating on the trade-offs the systems diagram clarified and explaining the ways in which they could use such an analysis in participative decision-making. This adds to the existing literature on how systems analyses can be used in participative settings between stakeholders.

The findings from Chapter 7 point to stakeholders being helped by the trade-offs between internal measures that were clarified. Previously, stakeholders had written off measures that were neither optimal in scenarios with increased LRD intensity, frequency, and duration or in scenarios without such increases. However, by introducing the concept of robustness to stakeholders, some measures became more desirable.

Although the hypothesis at the start of this research was that a systems analysis would also clarify the need for focus to be put on long-term viability and climate adaptation, this thesis research project was not able to confirm this. This was due to the fact that all participating evaluation interviewees were already convinced of the need to prioritize long-term viability and climate adaptation. However, each of the stakeholders did mention that the produced systems analysis could be used to educate individuals in the sector with less knowledge on climate adaptation.

This thesis research project has shown that a prototype systems analysis has been able to engage the interest of stakeholders in the IWT sector. This displays that there is a real-world application for more research on the understanding the trade-offs between measures. Future research can, for instance, focus on establishing relations quantitively instead of qualitatively. This could allow for more definite understanding of the systemic effects.

8.2.3 XLRM framework and Influence Diagram

This thesis research project produced a systems analysis using the XLRM framework and influence diagramming. The hypothesis was that this was a simple method of systems analysis and would hence be simple enough for most stakeholders to understand. The evaluation interviews confirmed that the XLRM framework in combination with influence diagramming can be used to convey robust decision analysis to stakeholders that are not learnt in policy analysis.

8.3 Societal Implications of Results

In the introduction of this thesis research project, the research was put in the context of the long-term viability of the IWT sector and the Dutch government's ambitions to shift more goods transport from road transport to IWT. The results of this thesis research project show that systems analyses can on the one hand empower IWT businesses to take more robust decisions, while on the other hand showing the Dutch government the need to invest into robust measures.

8.3.1 Empowering IWT Businesses

The uncertainty around the future navigability of the Rhine threatens the long-term viability of the IWT sector in the Netherlands by potentially harming the price competitiveness and reliability of the IWT sector (*Bosschieter, 2005*). The drought of 2018 shone light on the ramifications of low river depths and fired up the debate on mitigation amongst the IWT sector (*Quist, 2021*; *Schuetze, 2018*; *van Heel, 2020*).

Until now, IWT businesses have been adamant about the lack of government action on prioritizing the climate adaptability of the IWT sector. Following the extreme LRD period of 2018, an ensemble of stakeholders of the IWT sector (*Centraal Overleg Vaarwegen [COV]*) signed a letter addressed to the minister of Infrastructure and Water Management (I&W) requesting action to guarantee the future navigability of the Rhine (*Centraal Overleg Vaarwegen, 2018*). Although the COV makes a substantial argument and putting pressure on the government can be a strategic move, this thesis research project has outlined why government action is uncertain and relying on it can be detrimental to the long-term viability of the IWT sector (see '*Effects of External Developments*' on *page 63*).

Despite the increased awareness of the issue of increasing LRD periods and the signs that governments cannot guarantee that navigability will always be maintained, IWT businesses have conducted little action until now to adapt their businesses to climate change. This thesis research originally hypothesized that the lack of action could be ascribed to the lack of straight-forward, optimal solutions that IWT businesses could implement with higher degree of certainty that these solutions would be worth the investment. Most of the currently discussed solutions come with their trade-offs with regards to the uncertainty of future Rhine navigability (*Riquelme-Solar et al., 2014*). This was initially hypothesized to hold IWT businesses back from investing into measures that could increase their climate adaptability, thus possibly safeguarding their long-term viability.

This thesis research project conducted a robust decision analysis and focused on the robustness of measures with regards to different scenarios of external development of LRD occurrences. It was able to establish that there are differences in robustness of various measures (see *'Robust Trade-offs'* on *page 76*) and conclude that these insights were helpful to the decision-making of IWT businesses (see *'Stakeholder Evaluation'* on *page 76*). While various IWT stakeholders confirmed that uncertainty indeed held them back from committing to long-term measures (*AC.1; GA.1; GA.2; ISA.1; LSP.1; LSP.2; SK.2*), this thesis research project has been able to successfully demonstrate that a robust decision analysis can support IWT businesses in their decision-making. A robust decision analysis has been found to show potential in improving the overall understanding of what measures are available and what trade-offs can be attributed to certain measures. This allows IWT businesses to better understand how to make decisions that are robust, which could empower them to take the safeguarding of their long-term viability more into their own hands.

While not initially hypothesized, this research project has found that a lack in coordination amongst IWT stakeholders prevented focus to be put on the collective long-term objectives of the sector. Without coordination, individual IWT businesses usually prioritize short-term profits above providing reliable and affordable services during LRD periods as changing the reputation of the IWT sector cannot be done single-handedly. has been attested by stakeholders during evaluation interviews, a robust decision analysis therefore has value in coordinating decision-making between stakeholders. In the future, the simplicity and understandability of the systems analysis can be used to align IWT stakeholders behind a common strategy for the IWT sector that collectively aims to safeguard the long-term viability of the Dutch IWT sector.

8.3.2 Implications on Modal Shift

Besides being of personal concern to IWT businesses, the topic of viability of the Dutch IWT sector is also a concern to the ambitions of the Dutch government who intend to use the IWT sector as a means of making goods transport more environmentally sustainable. It is therefore in the interest of the Dutch government to support IWT businesses in their decision-making on climate adaptation measures. In addition to maintaining the waterway infrastructure, the Dutch government can work together with IWT businesses on implementing robust climate adaptation measures. This can firstly be done by initiating more research into the robustness of climate adaptation measures. Secondly, the Dutch government can coordinate action between IWT businesses by offering short-term incentives to IWT businesses who implement climate adaptation measures that have long-term benefits.

8.4 Methodological Limitations

This chapter explains the limitations of the results of the thesis research project with regards to the methodology used.

8.4.1 Qualitative Robust Decision Analysis

This thesis research project opted to use a qualitative robust decision analysis. Although the assumption of it being sufficient to use a qualitative robust decision analysis to explore the potential it had on the decision-making of IWT businesses remains correct, the qualitative approach has shown to be limited in its ability to provide definitive answers. The evaluation of the produced robust decision analysis is based on the judgement of IWT stakeholders rather than empirical evidence on how robust decision analyses would influence the decision-making of IWT businesses.

A quantitative robust decision analysis would be able to provide more conclusive results that IWT stakeholders could use to base their decision-making on. Within a focus group of various stakeholders from throughout the IWT sector, stakeholders can be first be requested to make decisions on internal measures without seeing the results of the robust decision analysis and then be requested to reiterate the decision-making process with the newly provided information. By testing the robust decision analysis in a case setting with more stakeholders, a more definitive answer could be presented on what the exact benefits of using robust decision analyses are.

8.4.2 More Objectives

This thesis research project only looks at the long-term viability of the IWT sector in terms of its ability to provide price competitive and reliable transport services. However, as has been mentioned often in interviews with IWT stakeholders, other objectives may become important in the future.

A pull-factor of the IWT that has been mentioned often is IWT's *CO2-efficiency*. Stakeholders in the IWT sector mention that they believe that shippers will continually demand transportation of their goods to become more CO2-efficient (LSP.1; LSP.2). Although the IWT sector currently has an advantage when compared to road transport services, the pressure to decarbonize further results as other modes of transport become more CO2-efficient through electrification. To compete with other modes of transport, IWT businesses believe that they need to focus on CO2-efficiency. Although the link to future navigability of the Rhine is less evident, external developments in new CO2-efficiency standards or competition from other modes of transport in terms of CO2-efficiency can make some of the climate adaptation measures less robust. For instance, travelling with empty pushed barges during non-LRD periods can be considered CO2-ineffecient, which may make the measure less robust.

8.5 Academic Recommendations

The results of this thesis research project justify three recommendations for further academic research:

1. Quantitative Modelling: conduct robust decision analysis using quantitative modelling techniques to attain a more definitive analysis that stakeholders can use to base their decisions on. A quantitative model can possibly function as a tool for IWT businesses to make robust decision in the short-term that guarantee their business's long-term viability
2. Focus Group Evaluation: use a focus group of various IWT stakeholders to provide more conclusive results on the potential of a robust decision analysis. A focus group session can test the potential of a robust decision analysis in enhancing collaborative discussion-making
3. New Knowledge Gaps: study the effects of implementing pushed barges and fleet diversity. This robust decision analysis points to these measures being relatively robust, however, not much research has been done on these measures and IWT stakeholders have expressed their interest on learning more about the potential of these measures

8.6 Managerial Recommendations

The results of this thesis research project justify two recommendations for IWT stakeholders to pursue:

1. Standardized Communication Object: use the robust decision analysis as a standardized communication object for discussions between stakeholders of the IWT sector. The findings from a robust decision analysis can be used during discussions between stakeholders to guide the discussion
2. Educational Tool: use the robust decision analysis to showcase the trade-offs between climate adaptation measures under various scenarios. Stakeholders who are less occupied with long-term decision-making (e.g., individual skippers) can be advised by larger entities such as a sector association or a contracting logistical service provider how to robustly adapt their business to changing navigational conditions

9 | Conclusion

This chapter presents a review on the conclusions of this thesis research project. By reflecting on the various research sub-questions posed at the beginning of the research, this chapter aims to give a structured review of what this thesis research project has been able to conclude.

SQ 1

What does the long-term viability of the Dutch IWT sector entail? (M)

This thesis research project has been able to conclude that the long-term viability for the Dutch IWT sector is inherently linked to the sector's ability to retain demand for their transport services. The two main pull factors that create demand for IWT services have been found to be IWT's price competitiveness and its ability to provide reliable transport services. Attempts at safeguarding long-term viability of the Dutch IWT sector, therefore, should focus on maintaining IWT services' price competitiveness and reliability.

SQ 2

What are the external developments affecting the long-term viability of the Dutch IWT sector? (X)

The external developments that affect the intensity, frequency, and duration of low river depth (LRD) periods and developments related to the demand for goods transport services have been found to influence the navigability of the Rhine. Climate change and river morphology impact the occurrence of LRD periods, while a potentially decrease in traditional bulk goods transport demand in favour of increased container transport demand can exert more pressure on IWT businesses to remain price competitive and reliable throughout LRD periods. These developments are uncertain in the extent to and the timeline within which they will develop. They are beyond the control of IWT businesses. This makes these developments uncertain and external to the sector.

SQ 3

What internal climate change adaptation measures could safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (L)

This thesis research project has assembled a list of nine climate adaptation measures that IWT business can independently implement which could safeguard the long-term viability of the Dutch IWT sector. The nine measures can be classified into measures that focus on fleet management, measures that make changes to logistical operations of IWT services and measures that involve using data in innovative ways to forecast transport demand and LRD periods.

Fleet management involves measures that adapt fleet composition such as increasing fleet diversity and making use of pushed barges and measures that involve making altercations to barges that reduce the draught of barges. Changes to logistical operations of IWT services can be enacted by taking alternative routes or using intermodal and synchromodal solutions. Finally, measures that use data innovatively are the use of river depth forecasting models, Vendor Managed Inventory practices and real-time data on riverbeds.

SQ 4

What internal climate adaptation measures can robustly safeguard the long-term viability of the Dutch IWT sector in the context of the external developments? (R)

The robust decision analysis conducted by this thesis research project has established that internal measures differ in their robustness under different scenarios with regards to the navigability of the Rhine. Measures that involve using data in an innovative manner are relatively robust due to their low investment costs and the fact that they change little to the current logistical processes. Measures with higher investment costs such as the deployment of low draught barges or measures that require continual expenditure like the reservation of additional transport capacity on other modes of transport are considered to be less robust when confronted with scenarios in which LRD periods occur less intensely, frequently or time-extensively and container transport is the predominant type of transport good transported by IWT businesses. These measures are too expensive for their return of investment. Measures like the use of pushed barges and the increase of fleet diversity show potential to be robust as it is conceivable that these measures can be productively used during non-LRD periods.

SQ 5

What is the potential of the robust decision analysis generated as a product of answering SQs 1 through 4 in supporting the IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector?

From interviews with different stakeholders in which the produced robust decision analysis was evaluated, it can be concluded that stakeholders understood the idea behind the robust decision analysis and supported the evaluation of measures on their robustness rather than their optimal performance. Stakeholders noted that understanding the robustness of internal measures was more important than understanding how the measures could work in one specific most likely scenario when making decisions on climate adaptation measures. Furthermore, interviewed stakeholders stated that the produced robust decision analysis could function as a standardized communication device that facilitated discussions between various IWT stakeholders. According to the interviewed stakeholders, this could allow for better collaboration between individual IWT stakeholders on the working towards the common objective of safeguarding the long-term viability of the Dutch IWT sector.

MQ

What is the potential of a robust decision analysis in supporting IWT businesses' decision-making on climate adaptation measures that could safeguard the long-term viability of the Dutch IWT sector?

By producing and evaluating a prototype robust decision analysis, this thesis research project has been able to show that robust decision analyses have the potential to support the decision-making of individual IWT businesses, as well as improve the communication between IWT stakeholders in collaborative decision-making arenas. Further research into more extensive robust decision analyses based on quantitative results and the use of focus group testing could provide more concrete and definitive answers on how robust decision analyses can support decision-making. For now, this thesis research project has been able to indicate that robust decision analyses show potential in supporting individual IWT businesses in their climate adaptation decision-making and in facilitating collaboration between these IWT stakeholders.

Glossary

All terms in this list are used in the research proposal. They are mentioned in italics throughout the report to indicate their occurrence in the list.

Term Entry	Dutch Translation	German Translation	Definition
ARCHIMEDES' PRINCIPLE	Wet van Archimedes	Archimedisches Prinzip	The mass of the loaded ship (including payload and consumables) is equal to the mass of the displaced volume of water
BEAM	Dwarsscheepse doorsnede	Schiffsbreite	The width of a vessel at its widest point
BED DEGRADATION	Erosie van rivierbodem	Tiefenerosion des Flussbettes	Erosion of the riverbed through sediment transport
BREAK BULK	Stukgoed	Massenstückgut	Goods that are transported as individual countable units in crates, boxes, pallets, and containers
CEMT-CLASS	CEMT-Klasse	CEMT-Klassifizierung	A set of standards for interoperability of large navigable inland waterways in Continental Europe
CENTRAAL OVERLEG VAARWEGEN (COV)	id.	N/A	A partnership between the CBRB, BLN-Schuttevaer, evofenedex, the VvW and NVvB that promotes common interests of waterway users on infrastructure in the Netherlands
CO_2-EFFICIENCY	CO_2-efficientie	CO_2-Bilanz	The measure of the total amount of carbon dioxide emissions that arise from an activity or the life cycle of a product in comparison to the productivity it delivers
COMPETITIVENESS	Concurrentiever-mogen	Wettbewerbs-fähigkeit	Ability to compete against of comparable nature (i.e., other modes of container transport)
CONVOY	Konvooi	Konvoi	A grouping of pusher barge and pushed barge(s)
DEADWEIGHT	Draagvermogen	Tragfähigkeit	The loading capacity of a ship measured in tonnes and consisting of payload and ship's consumables (mainly fuel and water)
DEEP UNCERTAINTY	N/A	N/A	A state in which parties to a decision do not or cannot agree on, the system model that relates action to consequences, the probability distributions to place over the inputs to these models, which consequences to consider and their relative importance
DISTRIBUTARIES	Rivieraftakking	Mündungsarm	A flow of water that branches off and flows away from a main stream channel into an ocean or a lake
DRAUGHT	Diepgang	Tiefgang	The vertical distance between the water surface and the bottom of the hull of a vessel (i.e., the keel)

EQUIVALENT WATER LEVEL (GLW)	Overeengekomen Lage Afvoer (OLA)	Gleichwasserstand	A statistically determined reference water level from which can be determined the water depths for a free-flowing river
EUROPEAN GREEN DEAL	Europese Green Deal	Europäischer Grüner Deal	A set of policy initiatives by the European Commission with the aim of making Europe climate neutral in 2050
FAIRWAY	Vaargeul	Fahrrinne	The marked-out part of a navigation channel between buoys and beacons that is often dredged to keep sandbanks from inhibiting navigation of larger barges
FREIGHT FORWARDER	Expediteur	Spediteur	A party that carries out the logistical planning of shipments for shippers. Usually, forwarders contract with transport carriers to provide shipment
GROYNE	Krib	Buhne	A short dam in the riverbed, perpendicular to the direction of current, interrupting river flow and limiting movement of sediment
HINTERLAND	Achterland	Hinterland	A geographic area serviced by a seaport. In the case of the Port of Rotterdam, this includes the Netherlands and large parts of Germany, France, Belgium, and Switzerland
INLAND PORT	Binnenhaven	Binnenhafen	A port located on an inland waterway, such as river, lake, or canal (e.g., Port of Duisburg)
INLAND WATERWAY TRANSPORT (IWT)	Binnenvaart	Binnenschifffahrt	A mode of transport that uses water vessels to transport over inland waterways such as canals, rivers, and lakes
INTEGRATED RIVER MANAGEMENT APPROACH	Integraal riviermanagement	Integrales Flussgebiets-management	An approach to river training project that aims for long-term stability and sustainable development, and coordination of various aspects of the river system, including morphology and landscape, river uses, and ecology (*Wang, Lee, & Melching, 2015*)
INTERMODAL TRANSPORT	Intermodaal goederenvervoer	Intermodaler Verkehr	The transportation of freight by using various modalities consecutively (*Economic Commission for Europe, UN, & European Commission, 2001*)
IPCC ASSESSMENT REPORT	IPCC-rapport	Sachstandsbericht des IPCC	Reports from the UN International Panel on Climate Change (IPCC) that reviews the latest climate science
IWT CARRIER	Rederij	Reederei	A person or company that trans-ports goods for shippers via IWT
LOAD FACTOR	Bezettingsgraad	Kapazitätsaus-lastung	The ratio of the current load to total vehicle freight load capacity
LOADING DRAUGHT	Aflaaddiepte	Abladetiefe	The maximum draught a vessel to which a vessel can be loaded because of diminished river depth
LONG-TERM SYSTEM ANALYSIS	Lange termijn systeemanalyse	Langfristige Systemanalyse	The process of "identifying, assessing and choosing among near-term actions that shape options available to future generations" (*Lempert et al., 2003, p. xii*)
LONGITUDINAL DAM	Langsdam	Leitdamm	A dam that is parallel to a riverbank
LOW RIVER DEPTH (LRD)	Laagwater	Niedrigwasser	Water level of a waterway that hinders navigation by providing less fairway depth

			than the maximum loading draught of vessels that commonly use that waterway
LOW WATER SURCHARGES	Laagwatertoeslag	Kleinwasserzuschlag	A surcharge that is levied on shippers during low river depth periods to compensate for additional costs due (e.g., additional logistical chartering, fuel expenses, etc.)
MODAL SHIFT	id.	Verkehrsverlage-rung	Replacement of a mode of transport (e.g., road transport, rail transport, IWT, etc.) by a different one
NAVIGABILITY	Bevaarbaarheid	Schiffbarkeit	The extent to which a waterway provides sufficient conditions including depth, width, and tranquility to allow for navigation
NORMALIZATION	Riviernormalisatie	Flussbau	To increase flood capacity and increase river discharge, projects such as river displacement and canalization were used to "normalize" the Rhine
NOZZLE	Straalbuis	Kortdüse	A tube placed around the propellers used to increase the efficiency of the propellers
PRECIPITATION SHORTFALL	Neerslagtekort	Niederschlagsman-gel	The cumulative potential evapotranspiration minus precipitation
PROPELLER TUNNEL	Schroeftunnel	Schraubentunnel	A tunnel is often installed around the protruding propeller shaft and propeller of a barge, from which more thrust from the water can be pulled
PUSHED BARGE	Duwbak	Schubkahn	A barge without own means of prolusion
RAINFALL DRIVEN SYSTEM	Regenval gedreven systeem	Regenfallbetrie-benes System	A river system that predominantly sources its water from precipitation rather than snowmelt
RHINE ESTUARY	Rijnmonding	Rheinmündung	A river delta in the Netherlands formed by the confluence of the Rhine and Meuse rivers
RHINE RIPARIAN STATES	Rijnoeverstaten	Rheinanlieger-staaten	The states of the Netherlands, Germany, France, and Switzerland (and sometimes Belgium) through which the Rhine flows
RHINE-CATCHMENT AREA	Rijnstroomgebied	Rheineinzugsgebiet	A basin area of 168,000 km^2 in the Netherlands, Germany, France, Luxembourg, Switzerland and Liechtenstein that comprises major tributaries (*Dieperink, 2000*)
RIVER GAUGE	Peil	Pegel	A location used to monitor and test water level and volumetric discharge of a stream
RIVER HYDROLOGY	Rivier hydrologie	Flusshydrologie	The properties of run-off processes in rivers
RIVER MORPHOLOGY	Riviermorfologie	Flussmorphologie	A river's planform and cross-section shape, which can change because of erosion and sedimentation processes
ROBUST DECISION ANALYSIS	Robuuste besluitvormingsana-lyse	Robuste Entscheidungsana-lyse	The process of searching, usually with quantitative analytical tools, for strategies that are robust, not optimal, under a large ensemble of scenarios
SCHEDULE RELIABILITY	Dienstregelings-betrouwbaarheid	Fahrplanzuverlässig-keit	
SEAPORT	Zeehaven	Seehafen	A port located on the shore of a sea or ocean that traffics in goods or passengers travelling over open sea (e.g., the Port of Rotterdam, Antwerp, etc.)

SHIPPER	Verlader	Verlader	A party in the logistical supply chain that requests to have goods transported
SKIPPER	Schipper	Schiffer	A.k.a. ship captain, an individual that operates a barge. Often skippers are freelance individuals who possess a barge and work under contract with a larger logistical service provider
SYNCHROMODALITY	Synchromodaliteit	Synchromodalität	The ability to switch real-time among different modes of transport according to the latest logistic information to utilize provide more efficient transport services (*van Riessen, Negenborn, & Dekker, 2015*)
SYSTEMS ANALYSIS	Systeemanalyse	Systemanalyse	An approach of studying a system (e.g., business, supply chain, political procedure, etc.) to identify its goal and create systems and procedures that will efficiently achieve them (*Webster, 1989*)
TONNE-KILOMETRE	Tonkilometer	Tonnenkilometer	A unit of measure of freight transport which represents the transport of one tonne of goods over one kilometre
VIABILITY	Levensvatbaarheid	Lebensfähigkeit	An ability to continue operations successfully
WATER LEVEL	Waterstand	Wasserstand	The elevation of the water surface relative to a specific vertical datum (in the Netherlands, Amsterdam Ordnance Datum: NAP)
XLRM FRAMEWORK	N/A	N/A	A framework that uses external uncertainties, policy levers, relationships, and measures to enable robust decision-making (*Lempert et al., 2003*)

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Appendices

A. Interview Coding

Appendix Table A.1 Interview Participants (Subjects)

SECTOR REPRESENTATION	INTERVIEWEE CODE	DATE OF INTERVIEW
Skipper	SK.1	26.09.2021
	SK.2	04.10.2021
Logistic Service Provider Representative	LSP.1	02.07.2021
	LSP.2	11.08.2021
	LSP.3	23.06.2021
IWT Sector Association Representative	ISA.1	04.06.2021

Appendix Table A.2 Interview Participants (Players)

SECTOR REPRESENTATION	INTERVIEWEE CODE	DATE OF INTERVIEW
Port of Rotterdam Representative	PR.1	30.06.2021
Shipper Representative	SH.1	01.07.2021
Shipper's Trade Association Representative	SHTA.1	29.09.2021

Appendix Table A.3 Interview Participants (Context Setters)

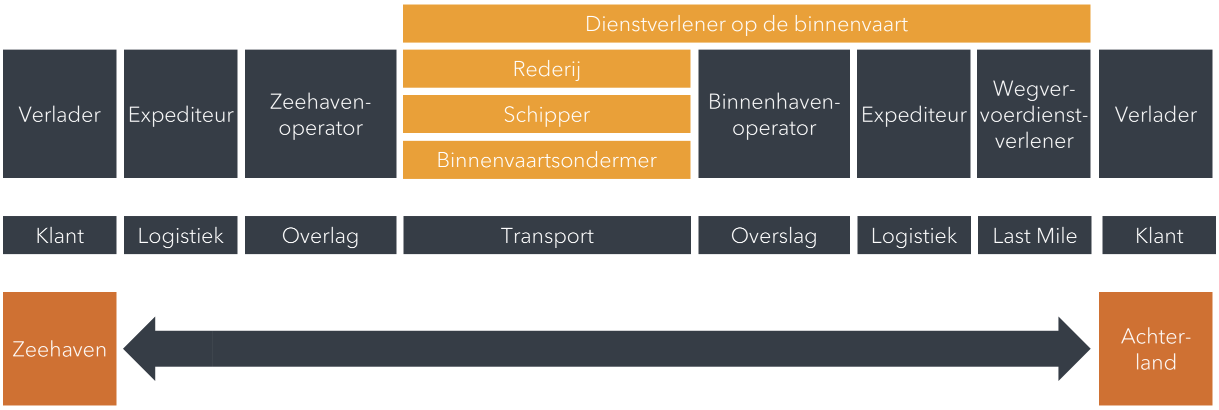
SECTOR REPRESENTATION	INTERVIEWEE CODE	DATE OF INTERVIEW
Government Authority Representative	GA.1	02.08.2021
	GA.2	02.08.2021
International Governing Body Representative	IGB.1	18.06.2021

Appendix Table A.4 Interview Participants (Crowd)

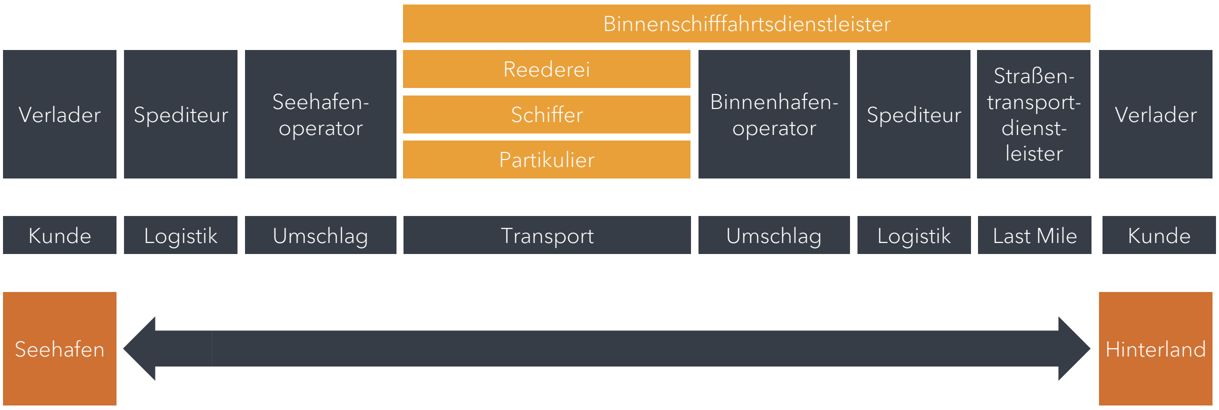
SECTOR REPRESENTATION	INTERVIEWEE CODE	DATE OF INTERVIEW
Technical Advisory Bureau Representative	TAB.1	02.06.2021
	TAB.2	04.10.2021
Academic	AC.1	
	AC.2	
	AC.3	

B. IWT Sector in Other Languages

These are translated diagrams of the diagram presented in '*IWT Businesses as a Problem Owner*' on *page 7*.



Appendix Figure B.1 | Logistieke keten van de binnenvaartssector
(Geel: probleemeigenaren; Blauw: andere belanghebbende)
(Oelfke & Oelfke, 2003)



Appendix Figure B.2 | Lieferkette des Binnenschifffahrtssektors
(Gelb: Problembesitzer; Blau: andere Stakeholder) (Oelfke & Oelfke, 2003)